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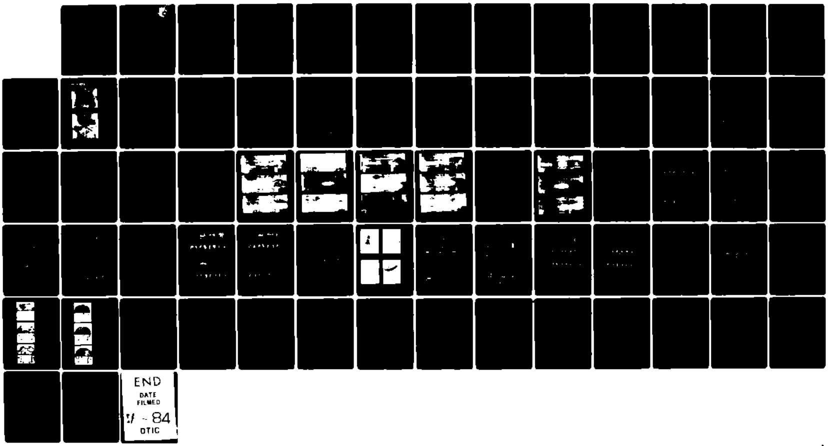

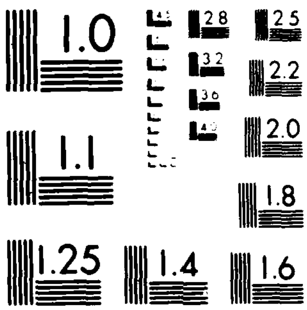
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AFWAL-TR-83-2081

MULTI-DUCTED INLET COMBUSTOR RESEARCH AND DEVELOPMENT

Universal Energy Systems, Inc.
4401 Dayton-Xenia Road
Dayton, Ohio 45432

November 1983

Interim Report for Period September 1982 – August 1983

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Flow visualization studies and fluid flow residence time measurements were conducted of a dual inlet side dump combustor configuration utilizing the Water Tunnel test rig of the Ramjet Technology Branch AFWAL/PORT Wright-Patterson AFB, Ohio. Tests were conducted of the side dump combustor for inlet duct angles of 30, 45 and 60 degrees and for combustor dome plate positions from 0 to 6 inches forward of the inlet ducts. The nozzle area to combustor area ratio for all testing was 0.29. Tests were conducted with total flow rates of 200, 300, and 400 gals. per min. to give inlet duct Reynolds —

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numbers of 125,640, 188,400 and 251,300 respectively. Preliminary visual observation investigations were also conducted of gas generator and symmetry flows. Engineering and technical support provided to other ramjet combustor test rigs of the Ramjet Technology Branch are detailed.

PREFACE

This report describes the research and development efforts conducted by Universal Energy Systems, Inc., on Project and Task 2308S110 Ducted Rocket Flowfield Characterization, contract #F33615-81-C-2074. These efforts were in support of the Ramjet Technology Branch (AFWAL/PORT) of the Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio .

The work reported herein was performed during the period 1 September 1982 to 31 August 1983, under the direction of the author, Mr. Gary D. Streby, Project Engineer. This report was released in August 1983.

This report is the second Interim annual report which details the scientific studies conducted utilizing water simulation to obtain fluid flow characteristics of the multi-ducted inlet side dump combustor. Also reported are the engineering and technical support efforts provided to other test rigs of the Ramjet Technology Branch. Interim technical report "Multi-Ducted Inlet Combustor Research and Development", AFWAL-TR-82-2101, details the first year efforts of the thirty-six month research program.

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SYMBOLS

1. C Calculated
2. GPM Gallons Per Minute
3. Ht Dome Plate Height From Reference Point
4. M Measured
5. R_{e_I} Inlet Duct Reynold Number
6. T_R Residence Time
7. $\dot{V}$ Fluid Flow Rate

1. α *Inlet Duct Angle*
2. $\emptyset$ Radial Angle About Combustor Axis

SECTION I
INTRODUCTION

Future Air Force requirements for supersonic air-breathing tactical missiles will require the development of advanced propulsion systems. These propulsion systems will have to operate at high altitudes and high mach numbers and be cost effective, simple in operation, and compact. The propulsion system design which best fits these design parameters is the ramjet combustor. Ramjet combustors operate most efficiently at high mach numbers and altitudes; work on the ram compression principle requiring no moving parts; and can be designed to be small and compact. In order to realize the full potential of the ramjet combustor design, research and development efforts are necessary to obtain data of combustor performance characteristics and design parameters. This information is presently obtained from actual hot combustor testing and from fluid flow simulations.

Universal Energy Systems, Inc. (UES) has completed the second year of a three year research and development effort to obtain qualitative and quantitative data of advanced ramjet combustor designs utilizing the AFWAL/PORT Water Tunnel test rig. These efforts are to obtain cold flow fluid dynamic characteristics for variations in basic combustor design parameters. Studies have included fluid flow observations using flow visualization techniques and the measurement of residence times for the various configurations.

Presented in this report are details of the engineering and technical efforts accomplished by UES to improve and upgrade the research test rigs of the Ramjet Technology Branch (AFWAL/PORT) and the results of ramjet combustor research conducted using the Water Tunnel test rig. The results obtained from the Water Tunnel test rig include visual and photographic data as well as residence combustor times. Test results are presented and discussed and preliminary conclusions made for the results obtained.

SECTION II
IMPROVEMENTS AND SPECIALIZED STUDIES

Universal Energy Systems, Inc., in addition to conducting advanced combustor research efforts, has provided engineering and technical support to the Water Tunnel test rig and other related test rigs of the Ramjet Technology Branch of the Aero Propulsion Laboratory. These services have been provided to accomplish test rig modifications and improvements; to maintain specialized test instrumentation; and to conduct unique experimental investigations.

2.1 WATER TUNNEL TEST RIG SUPPORT

2.1.1 Computer Data Acquisition System

During this reporting period UES received and installed a new Mod Comp MODACS III computer system to support the Water Tunnel test rig. The new data acquisition system became a new satellite unit of the computer network of the Aero Propulsion Laboratory. After preparation and checkout of data acquisition software, the computer system was utilized to collect, reduce, store, and analyze Water Tunnel test data.

2.1.2 High Intensity Light Source Fixture

An improved High Intensity Light Source mounting fixture was designed, fabricated, and installed onto the Water Tunnel test rig. The new mounting fixture improves operation and the flow visualization capabilities of the light source. The High Intensity Light Source can now be rotated around the combustor test section to allow for the observation of radial planes of the combustor flow field. The light source can still be positioned at any longitudinal station of the test section. The High Intensity Light Source and fixture are shown in Figure 1(a) and in various positions of operation in Figure 1(b).

2.1.3 Improved Gas Generator Section

A new combustor Gas Generator section was designed and fabricated for the Water Tunnel test rig. The improved Gas Generator section allows for the injection of water flows into the dome region while still permitting visual observations at the head end of the combustor test section. Only preliminary checkout tests have been conducted of Gas Generator flows with simple dome plate injector

(a)

(b)

Figure 1. High Intensity Light Source and Mounting Fixture

configurations. The results of these initial tests are presented in Section VII. A more extensive study of Gas Generator flows is planned in the next years effort.

2.1.4 3-D Computer Code Development

UES provided engineering support for the development of a three dimensional computer code for use in the analysis of the multi-ducted inlet side dump combustor configuration. UES subcontacted the services of Dr. Pratap Vanka of Argonne National Laboratories to perform computer simulation studies. Dr. Vanka developed computer code modifications to describe the flow fields and flow characteristics of the dual inlet side dump combustor configuration. Dr. Vanka completed several computer test runs which described the internal flow fields of side dump combustor configurations and presented informal lectures to UES and AFWAL/PORT personnel to discuss analytical characterization methods and their use. The results of Dr. Vanka's work is detailed in Reference 1.

2.2 COLD FLOW CHANNEL SUPPORT

UES has continued to provide specialized technical support to assist in the conducting of cold flow studies and gas sampling research related to the multi-ducted inlet side dump combustor configuration. These efforts have involved the Cold Flow Channel and 30 Inch HWT test rigs location in Building 450. During this reporting period a number of important tasks were accomplished which increased the capabilities of the test rigs and improved the quality of test information. The following list are major tasks which were supported and completed.

- Design, fabrication, and installation of a new control console for the Cold Flow Channel test rig.
- Completion of oil flow test series in the Cold Flow Channel test rig to obtain flow visualization data.
- Provided assistance in the design and fabrication of a new gas sampling probe.
- Installed, checked out, and performed calibration of a new transducer bank for use with the 30 Inch HWT test rig.
- Provided assistance in the design of a new traverse probe drive system and made improvements and modifications to the present L.C. Smith probe drive unit.

- Fabrication of gas columns and molecular sieves for use in gas sampling experimentation.
- Modification of the Ion Mass Spectrometer test equipment as required for test purposes.

In addition to these tasks, UES personnel provided support to conduct numerous testing operations using the Cold Flow Channel and the 30 Inch HWT test rigs. All these efforts were directed at obtaining information on fuel mixing processes of advanced combustor configurations.

2.3 BURNER THRUST STAND TEST RIG SUPPORT

2.3.1 Holographic Fuel Droplet Study

UES subcontracted the engineering and technical services of Spectron Development Laboratories of Costa Mesa, California to conduct a combustor fuel droplet study utilizing the Burner Thrust Stand test rig located in Building 18C. This study was to examine fuel droplet size distributions and dispersion for various fuel injection methods and for different flow parameters using hot combustor flows. The holographic study was conducted from the 23rd of September to the 21st of October 1982. Laser holograms were made for each test condition and developed on-site for preliminary review. After the testing phase of the program was completed the holograms were taken to Spectron Laboratories for further analysis. The results of the holographic study are presented in Reference 2. After analysis, a set of selected holograms were furnished to AFWAL/PORT.

2.3.2 Exhaust Nozzle Control System

Efforts were undertaken by UES to modify and upgrade the Burner Thrust Stand test rig. Dynamics Controls, Inc., Dayton, Ohio was subcontracted by UES to design, fabricate, and install an exhaust nozzle control system onto the Burner Thrust Stand. The system maintains allowable nozzle clearance tolerances during hot combustor operations when thermo movement of the exhaust nozzle occurs. A complete operations manual for the system and detailed design drawings were provided to AFWAL/PORT as part of this support.

SECTION III
WATER TUNNEL TEST FACILITY

The Ramjet Technology Branch's Water Tunnel test rig facility is a closed loop water tunnel for the simulation of internal fluid flow dynamics of ramjet combustor configurations. The Water Tunnel is located in Building 18E, Room 22, Wright-Patterson AFB, Ohio and is capable of circulating up to 1500 gallons of water per minute. A schematic diagram of Water Tunnel test rig, components, and system arrangement is presented in Figure 2. All piping in the Water Tunnel system is of PVC plastic and the test section is constructed of clear plexiglas. The clear plexiglas test section allows for complete observation of flows in the test configurations. The Water Tunnel test rig is capable of testing full scale single and multi-ducted inlet ramjet combustor configurations over an inlet duct Reynolds number range of 0.4 to 4.0 million per foot. Simulations of associated combustor flows such as gas generators and fuel injectors are also possible. Support systems to the Water Tunnel test rig include an air/dye injection system, a laser/optical detection system, and a high intensity light source.

The air/dye injection system is capable of injecting air bubbles or colored dye into combustor configurations for flow visualization or for residence time measurements. Injections are made through a variety of specialized probes or test ports and can be controlled manually or by a precison timer control. Pulse durations as short as 0.01 second are possible. Dye injections are made through a vernier metering valve to allow for accurate control of the quantity of injected dye.

The laser/optical detector system consists of a Spectra Physics 0.05 watt Argon laser, two RCA 6655A photomultiplier detector tubes, and various beam splitting and alignment optics. This system is utilized for the detection and measurement of injected dye concentrations to obtain concentration time histories for residence time determinations.

The high intensity light source consists of a high voltage D.C. power supply which powers a high intensity mercury lamp. The light source output is adjustable up to 65,000 lumens at 1000 volts D.C. The mercury lamp generates an intense source of radiant energy which is

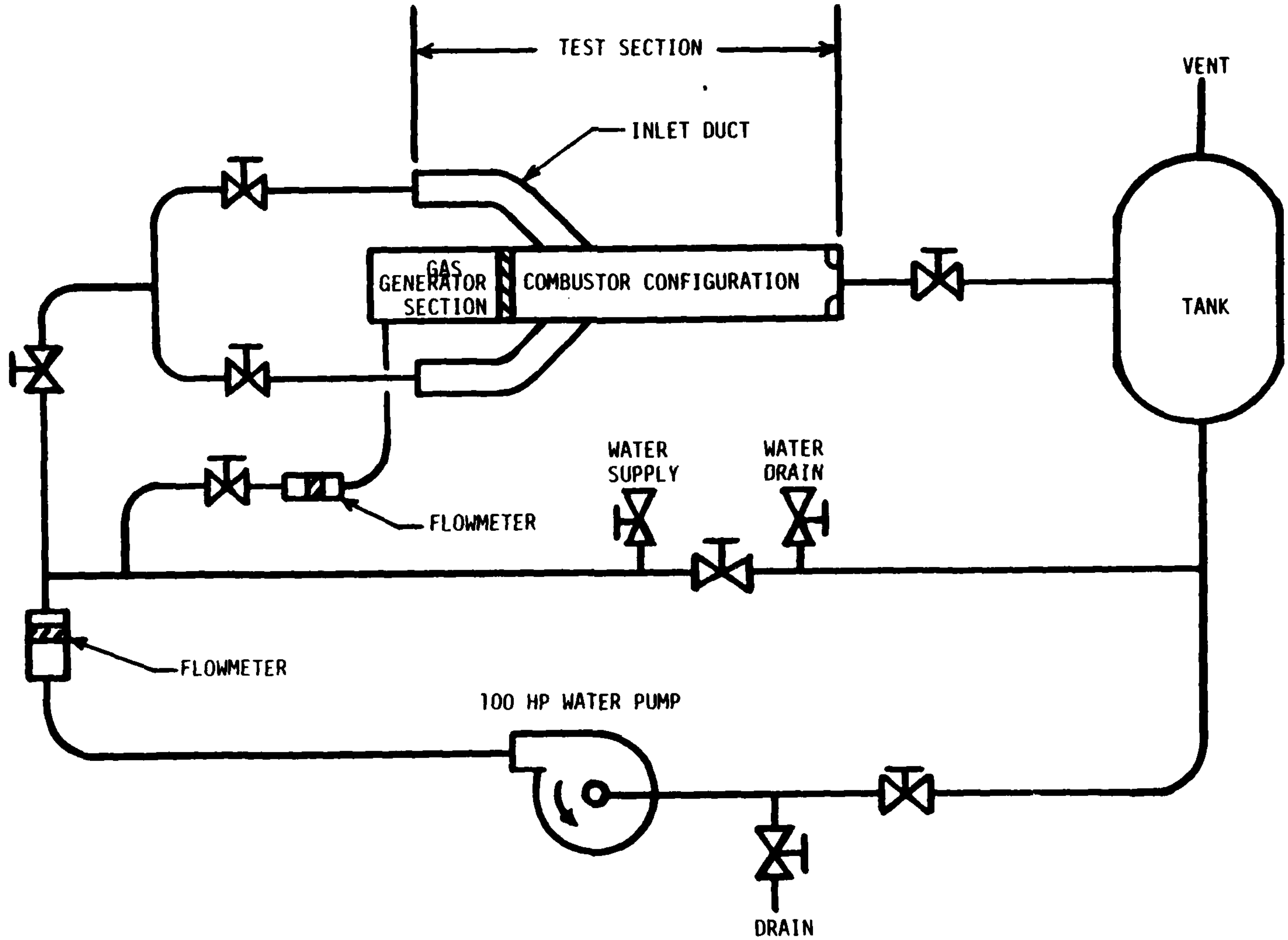


Figure 2. AFWAL/PORT Water Tunnel Facility Schematic

focused to a narrow plane beam. The narrow light beam is used to luminate injected air bubbles which describe internal flow patterns. Various lamp fixtures are available to position the light plane perpendicular or parallel to the combustor axis and can be positioned to any point along the combustor axis.

SECTION IV
MULTI-DUCTED INLET COMBUSTOR CONFIGURATION

The test configuration under investigation in this research program is the dual inlet side dump combustor. The test configuration is made up of two rectangular inlet ducts, a combustor section, a gas generator section, and an exhaust nozzle. A schematic diagram showing physical dimensions of the test configuration is presented in Figure 3.

Test hardware is available that allows the two inlet ducts to intersect the combustor at inlet angles of 30, 45, or 60 degrees. Test data reported herein were obtained for all three test configurations. The centerline of the inlet ducts intersect the combustor section at the same axial station and are located radially at 90 degrees to each other. The internal dimensions of the inlet ducts measure 2.0 by 2.75 inches. The upstream edge of the inlet ducts is taken as the combustor longitudinal zero reference point. Longitudinal measurements downstream of the zero reference point are positive and are negative upstream of the zero reference point, refer to Figure 3.

The combustor section is a cylinder with a 6.0 inch I.D. and measures 39.0 inches in length from the combustor longitudinal zero reference point to the exit nozzle. The combustor dome plate is located at the upstream end of the combustor section and can be positioned axially from the zero reference point to approximately 10.0 inches forward of the inlet ducts. Various configurations of the dome plate are available to simulate gas generator flows or fuel injection techniques. Residence time test results reported herein are for a solid flat dome plate with no gas generator flow. The exit nozzle of the combustor is removable to allow different nozzle exit area to combustor area ratios to be tested. Nozzle exit area to the combustor area ratios of 0.20, 0.29, and 0.39 are available. A nozzle exit area to combustor area ratio of 0.29 was utilized during all testing described in this report.

The gas generator section of the multi-ducted inlet test configuration is designed to simulate gas generator flows or fuel injection. Water flow can be introduced to the combustor section through specially designed dome plates and can be regulated in proportion to the

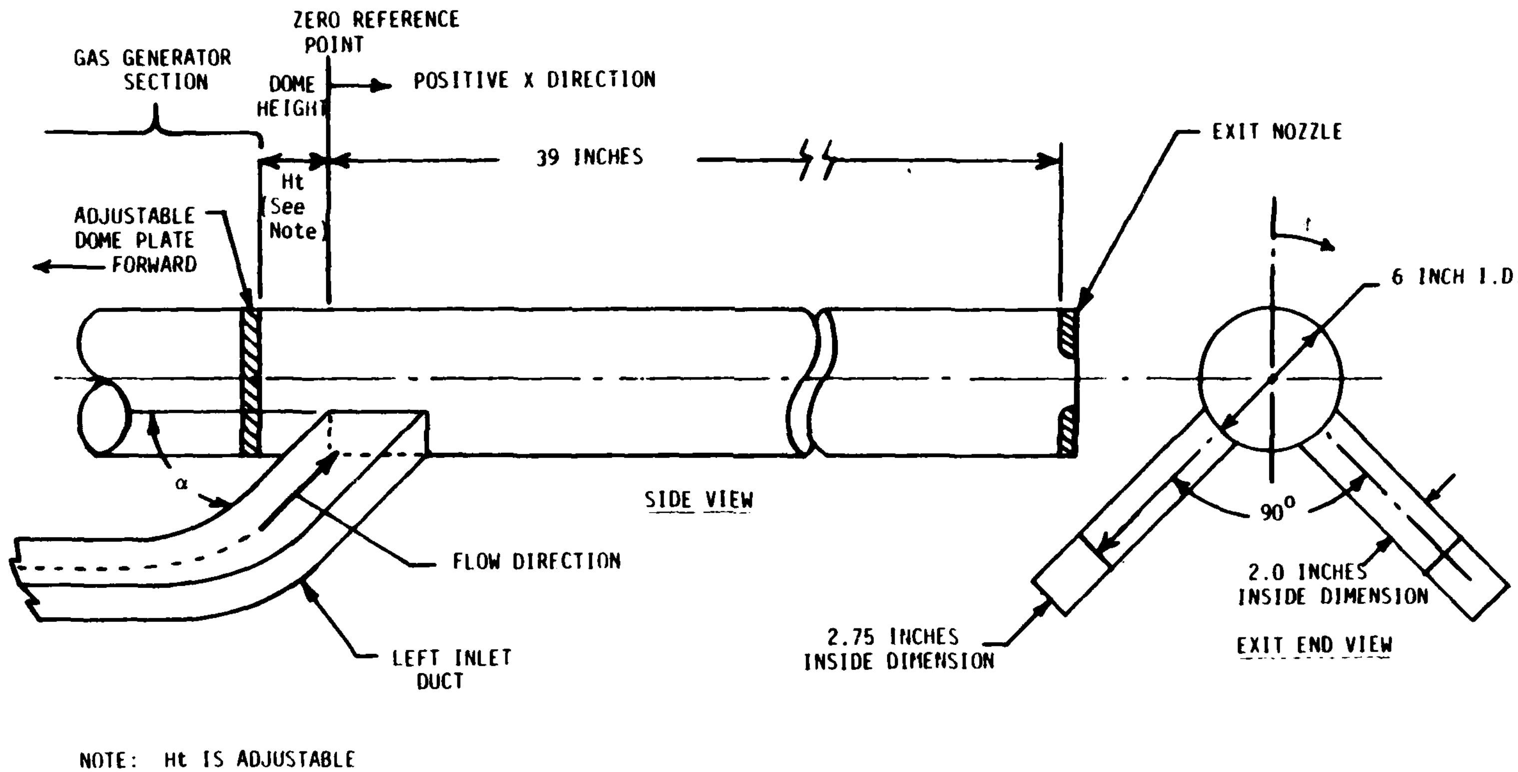


Figure 3. Dual Inlet Side Dump Combustor Configuration

total tunnel flow. The gas generator section is designed to allow for visual and photographic observation of the internal flow patterns.

SECTION V
INSTRUMENTATION

The AFWAL/PORT Water Tunnel test rig has been improved and modified by UES in an effort to upgrade the capabilities of the facility and enable research studies to be conducted of the multi-ducted inlet side dump combustor. The Water Tunnel laser/optical detection system has been upgraded and is now capable of detecting minute concentrations of injected dye at various points within the combustor configuration. A Mod Comp MODACS III computer data acquisition system has been installed and placed into operation for the sampling, reduction, and analysis of test data. Figure 4 shows a diagram of the laser/optical detection system depicting the relationship of the various components to the test configuration. Shown in Figure 5 is a block diagram of the instrumentation system utilized for the residence time testing phase of the research program.

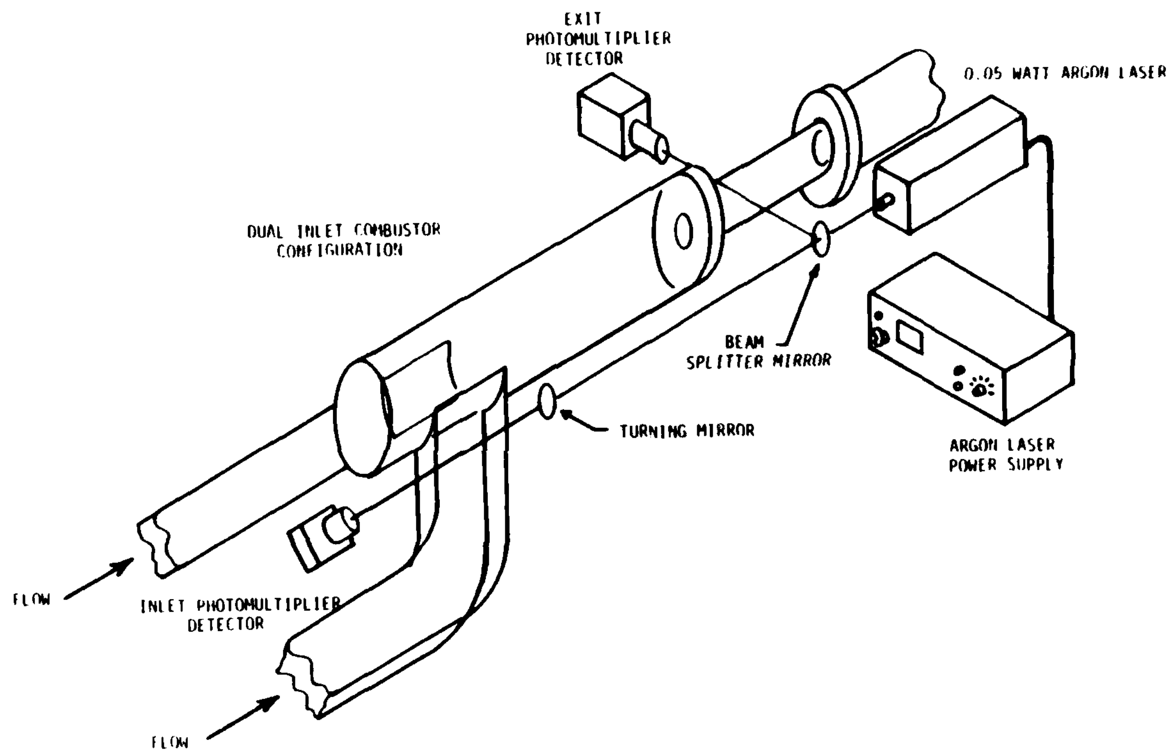


Figure 4. Laser/Optical Detection System Diagram

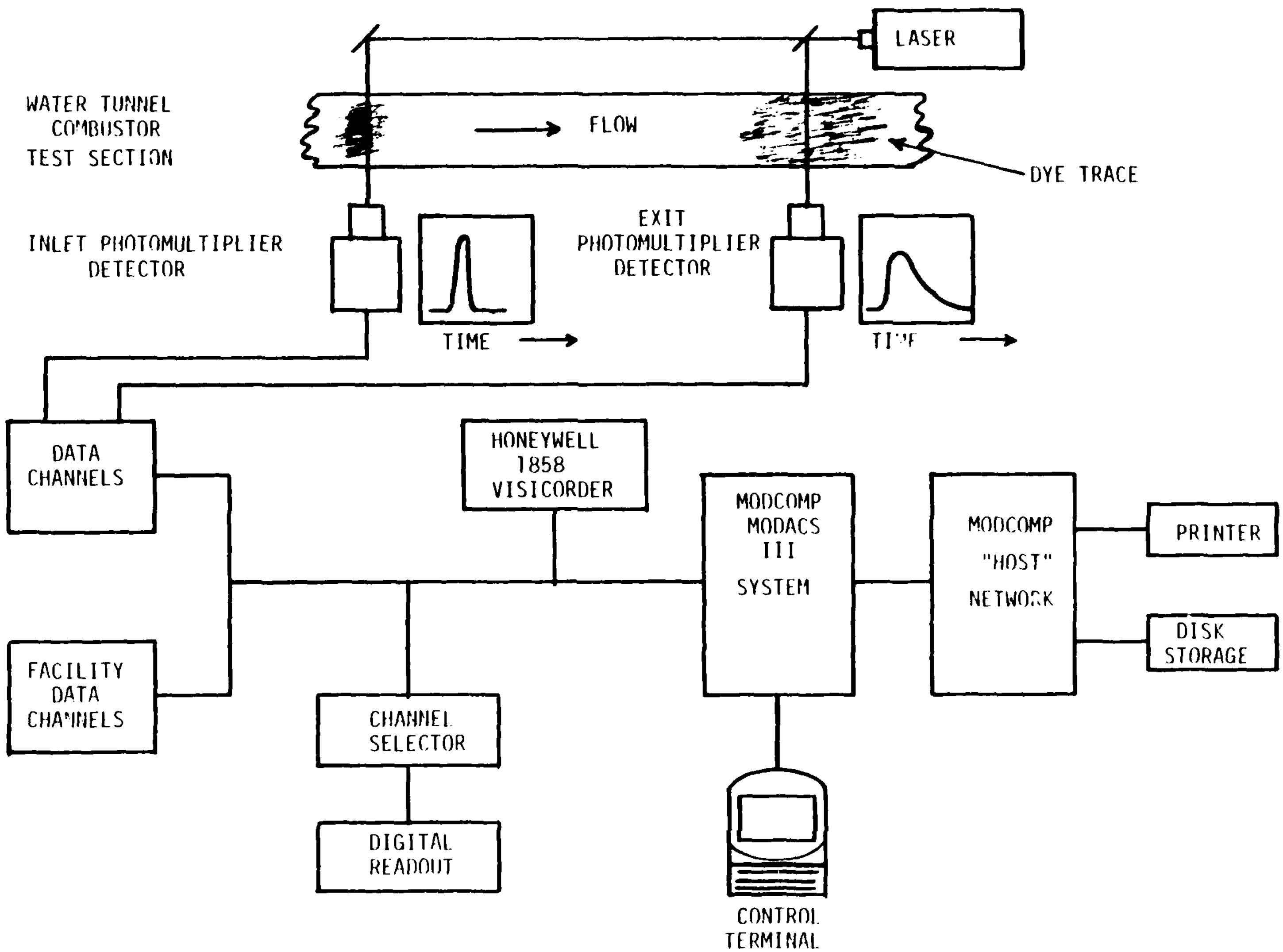


Figure 5. Block Diagram of Water Tunnel Instrumentation System

SECTION VI
TEST PROGRAM

The UES test program for achieving the desired objectives of the research and development program has been conducted in three related areas. These areas include the refinement of test methods and hardware to provide consistent and reliable test methods; the conducting of an extensive visual study of internal fluid flow patterns of test configurations; and the conducting of residence time testing of the dual inlet side dump combustor.

6.1 IMPROVEMENT OF TEST METHODS AND HARDWARE

In order to properly conduct the residence time studies of the multi-ducted inlet combustor configurations it was first necessary to perform a study of dye injection probes and injection procedures. It was desirable to have the capability to inject a minute quantity of colored dye tracer into the fluid stream that would disperse completely, quickly, and uniformly in a small volume of the fluid. This dye tracer would then be the simulus to the system which could be detected and analyzed to determine residence times.

The test program to develop the best dye injection test methods and hardware has been a progression of tests and modifications. The injection probe has progressed from a simple straight or bent tube to a complex configuration. Presented in Section VII are the results of five configurations of injection probes showing the progression of improvements in dye injection probe designs.

6.2 FLOW VISUALIZATION STUDIES

An important aspect of the research effort was to obtain an understanding of flow field characteristics and the flow processes of combustor configurations. This understanding was best achieved through visual observations of liquid flow patterns using special visual techniques. The method utilized with the Water Tunnel test rig was the high-lighting of dispersed air bubbles in the water flow with a high intensity mercury lamp. The light was focused to a narrow beam approximately 1/4 inch wide and shown through the clear plexiglas test section. Visual and photographic observations were then made through the

side or dome plate end of the combustor configuration. Presented in Section VII are sketches, made from visual observations, for the three inlet configurations (30, 45, and 60 degrees) which were studied. Each series of sketches show air bubble flow patterns at several longitudinal stations for various dome plate locations. Also presented are sketches of flow patterns at three radial stations around the axis of the 60 degree combustor configuration for several dome plate positions.

Observations were also made of preliminary investigations into specialized combustor flow problems such as gas generator flows and symmetry flow evaluations. The sketches obtained from these investigations are also presented in Section VII.

6.3 RESIDENCE TIME STUDIES

The 30, 45, and 60 degree inlet configurations of the dual inlet side dump combustor were tested to determine combustor residence times. Tests were conducted at Water Tunnel total flow rates of 200, 300, and 400 gallons per minute and for combustor dome plate locations from 0.0 to -6.0 inches from the longitudinal zero reference point (Refer to Figure 3). The combustor dome plate was moved in increments of 0.5 inches for the 300 gallon per minute flow rate and in increments of 1.0 inch for the 200 and 400 gallon per minute flow rates. The inlet duct Reynolds numbers for the water flow conditions are given in Table 1. The inlet duct Reynolds numbers are based on the hydraulic diameter determined from the inlet duct cross-sectional area. All residence time tests were conducted at water temperatures between 80 and 90 degree Fahrenheit.

TABLE 1

INLET DUCT REYNOLDS NUMBERS

TUNNEL TOTAL FLOW RATE (GPM)	INLET DUCT REYNOLDS NUMBER (Re_I)
200	125,640
300	188,480
400	251,300

SECTION VII
DATA PRESENTATION

The data presented herein detail the results obtained by UES in conducting fluid flow simulation studies of advanced combustor configurations utilizing the AFWAL/PORT Water Tunnel test rig. Presented in the following paragraphs are the results of a dye injection probe design investigation, a study of combustor flow field patterns using visual and photographic methods, and the results of residence time testing for three inlet configurations of the dual inlet side dump combustor.

7.1 INJECTION PROBE INVESTIGATION

The injection probe investigation was undertaken in an effort to design a dye injection system that would provide a repeatable and consistent dye tracer stimulus to the fluid flow system. A dye tracer input pulse was required that would be dispersed completely throughout a small volume of the inlet fluid and have a short time duration. The dye tracer input could then be used as a stimulus to the fluid flow system and the response of the system determined with the appropriate concentration detection devices. Presented here are the results of an investigation that was accomplished to design the dye injection probe presently utilized for dye injections to obtain residence time measurements and also used for air bubble injection for visual studies.

Presented in Figure 6 are drawings of the injection probe designs which were investigated. For this investigation the Water Tunnel total flow rate was 300 gallons per minute, therefore, the inlet flow rate being observed was 150 gallons per minute. Each dye injection pulse was for 0.01 second duration. The photographs shown in Figures 7, 8, 9, 10, and 11 were taken from high speed movie film shot at 400 frames per second. The three photographs of each injection probe design show the dye injection at three time intervals after injection. The top photograph of each series was taken at 0.05 seconds, the middle photograph at 0.113 seconds and the bottom photograph at 0.175 seconds. The Reynolds number for the flow in the inlet duct was 188,480.

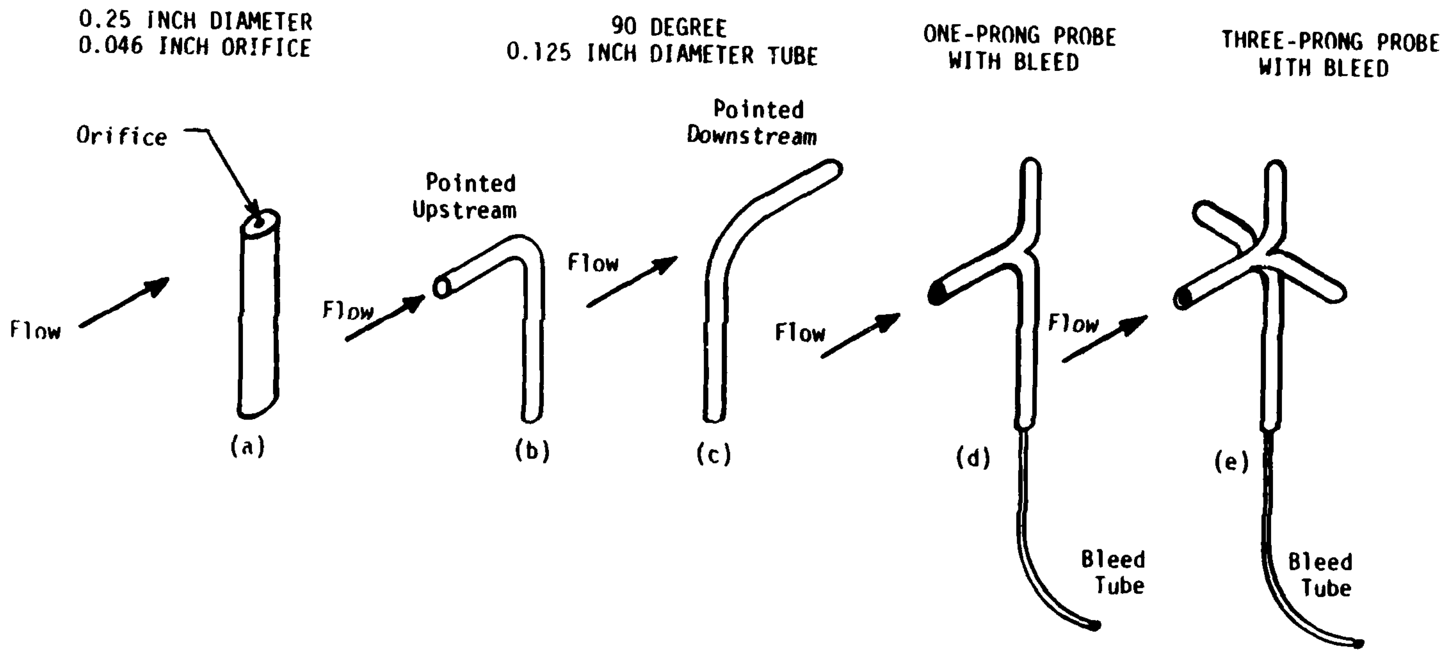
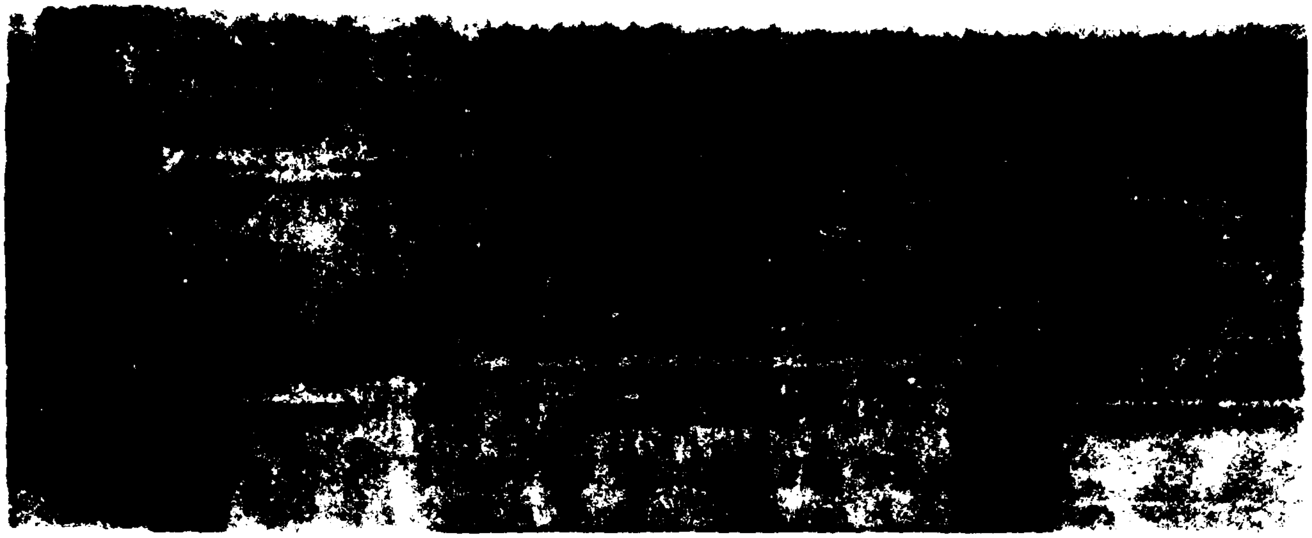


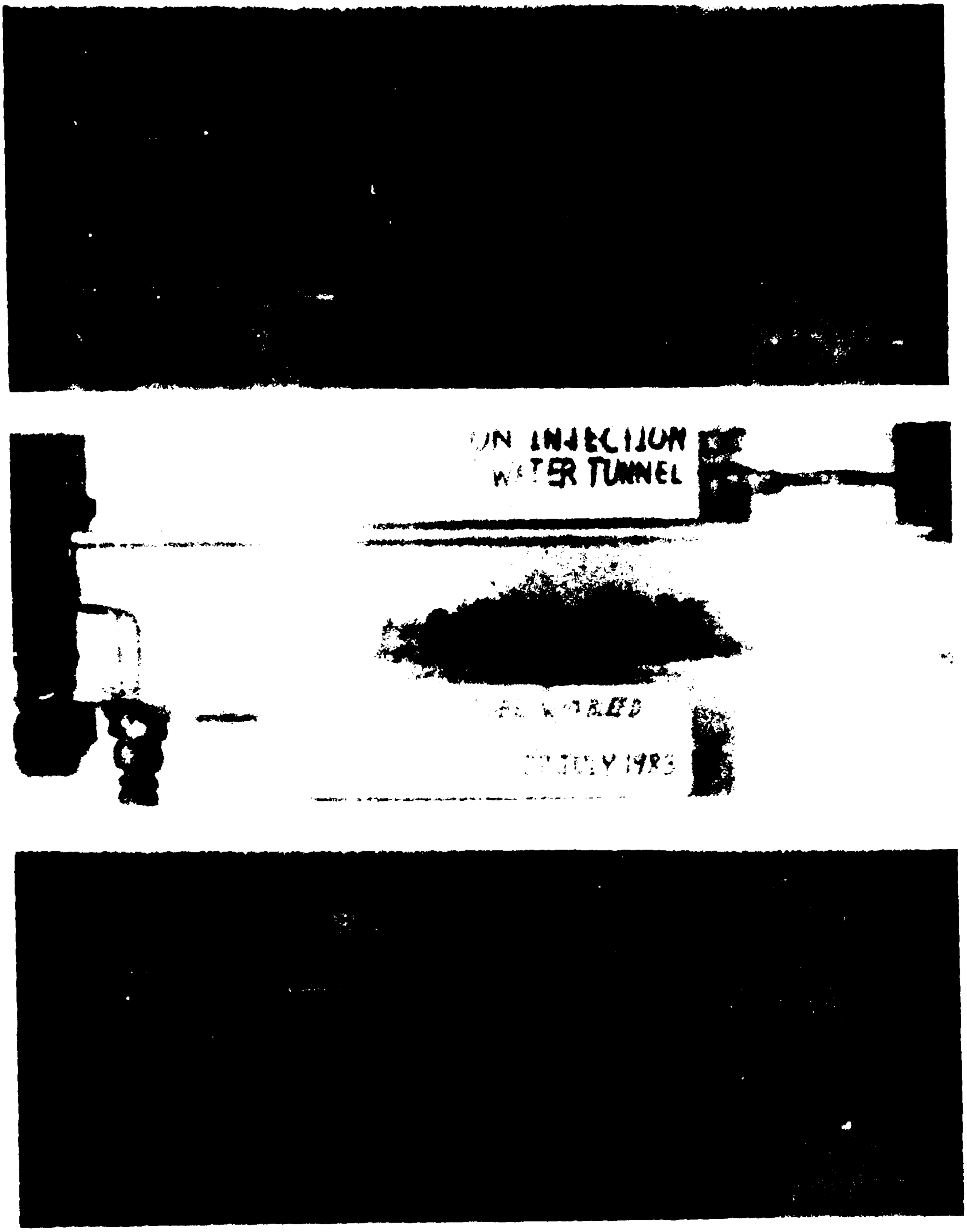
Figure 6. Dye Tracer Injection Probe Designs

The first sequence of photographs, Figure 7, show a dye injection pulse from the 0.25 inch diameter probe with a 0.046 inch diameter injection orifice (See Figure 6 (a)). This probe was designed from typical liquid fuel injectors utilized in hot combustor testing. It can be seen that the dye was drawn down into the wake of the probe not allowing the dye to completely disperse. Also, the dye was trapped in the wake causing the dye trace to extend the full length of the inlet duct. This design would provide an unsuitable input pulse to the system.

The second and third sequence of photographs, Figures 8 and 9, show a dye injection pulse from the 90 degree bent 0.125 inch diameter stainless steel tube probe design (See Figure 6(b) and (c)). Figure 8 shows the results for the probe pointed upstream into the flow and Figure 9 shows results for the probe pointed downstream. It can be seen that when the probe is pointed upstream the injected dye tends to form a long concentrated pulse which is slow to disperse. The dye does not completely fill the inlet duct in the path shown. It should also be noted that because of flow pressure fluctuations additional dye enters the stream causing a trail of dye behind the main pulse. This additional dye injection could cause errors in the response of the system. Another important observation to be noted for this probe design was that a small portion of the dye moved down into the wake of the probe causing good dispersion for a portion of the dye. This flow characteristic was used in the design of improved injection probes. When the 90 degree tube probe was pointed downstream the injected dye pulse stayed concentrated and was slow to disperse completely into the surrounding fluid. The trail of dye behind the dye pulse for this case was worse than for the upsteam case.

The fourth sequence of photographs, Figure 10, show a dye injection pulse from the one-prong probe design (See Figure 6(d)). This probe design was a consequence of observations made of the 90 degree bent tube probe pointed into the fluid stream. Since the injected dye follows the wake of the probe tube, it was reasoned that additional protrusions would help disperse more of the injected dye. The one-prong probe was a 0.125 inch diameter 90 degree bent tube with a 90°degree bent tube protrusion





[illegible] Tube Probe [illegible]

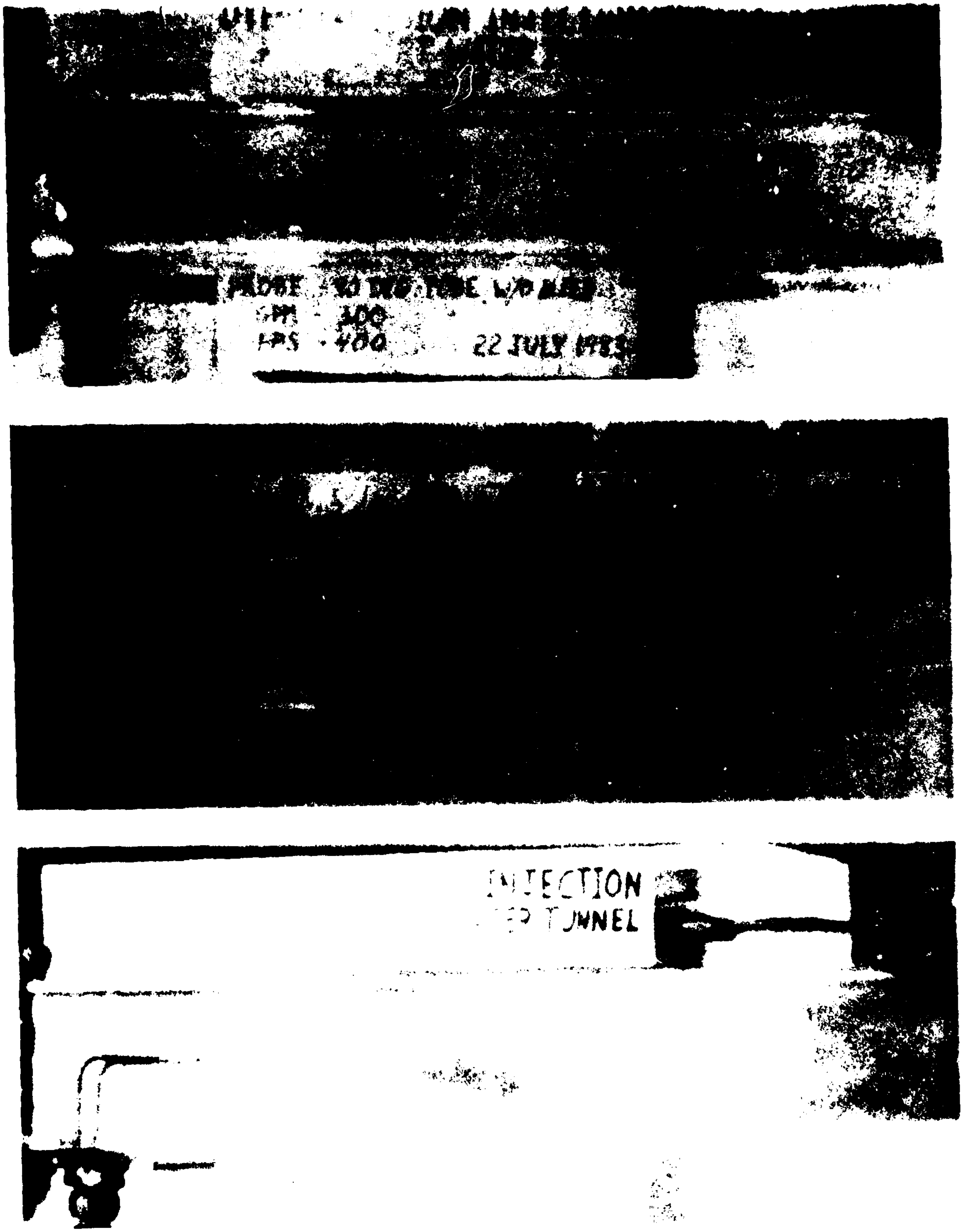


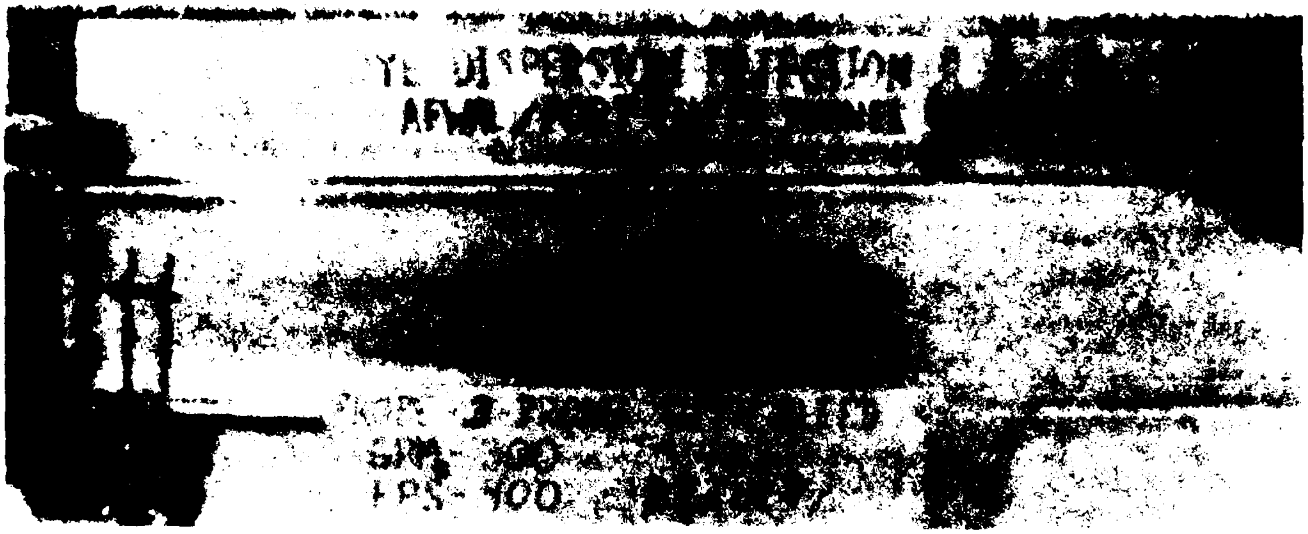
Figure 9. 90 Degree 0.125 Inch Diameter Tube Probe - Pointed Downstream

on the top of the probe. In addition, a 0.063 inch diameter tube was placed inside the probe with one end just inside the probe opening. This smaller tube was brought outside the probe to bleed off fluid from the system. This technique eliminated the trail off of dye from the probe after injection allowing for a cleaner pulse. The photographs show that dye dispersion was good in the vertical direction and the dye pulse completely dispersed in the fluid path. The typical length of the dyed fluid pulse was approximately 8 to 9 inches.

The fifth injection probe design, Figure 6(e), is an improved version of the one-prong probe design. This probe has two additional prongs added to the probe in the horizontal plane. This modification insures that dye dispersion will occur in both the vertical and horizontal planes of the inlet duct. Figure 11 shows that the dye pulse dispersion was uniform in concentration, short in length, and occurred in a relatively short distance of the fluid path. The overall length of the dyed fluid was approximately 6 to 8 inches in length at the end of the inlet duct. At the flow rate tested the input dye pulse time interval would be on the order of 0.06 to 0.08 sec. This injection probe design was used in conducting the residence time tests and flow visualization studies reported herein.

7.2 VISUAL OBSERVATIONS STUDIES

Visual observations have been an important aspect of the research and development studies of advanced ramjet combustors conducted using the AFWAL/PORT Water Tunnel test rig. These studies aid in the basic understanding of the fluid flow characteristics and the effects of configuration parameter changes. Visual information was obtained through the use air bubble injection and a high intensity light source. The high intensity light source was focused to a narrow plane of light which illuminated air bubbles in a thin slice of the moving fluid in the test section. Hand drawn sketches, photographs, and high speed movies were made of the air bubble traces for various combustor configurations. Presented herein are hand drawn sketches and photographs showing the flow patterns observed for the three inlet configurations of the side dump combustor. Also presented are visual observations of preliminary investigations into gas generator effects and combustor symmetry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FPS-400

simulation flows. All tests were conducted at a tunnel total flow rate of 300 gallons per minute.

Presented in Figures 12, 13, and 14 are flow pattern sketches for the 30, 45, and 60 degree inlet configurations respectively. Drawings were made at several combustor longitudinal stations for dome plate locations of 0, -1, -2, -3, and -4 inches. Figure 15 presents representative photographs of combustor flow patterns at longitudinal stations of -2, 0, 2, and 8 inches for the 60 degree inlet configuration with the dome plate located at -2.0 inches. Shown in Figure 16 are sketches of radial flow patterns for the 60 degree inlet configuration for dome plate locations of 0, -2, -4, and -6 inches. These drawings were obtained by placing the high intensity light beam parallel to the combustor axis and rotating the light source about the axis. Combustor radial positions of 0, 22.5, and 45 degrees were sketched for each dome plate configuration. Radial positions were measured from the top of the combustor in the clockwise direction when viewed upstream from the combustor nozzle.

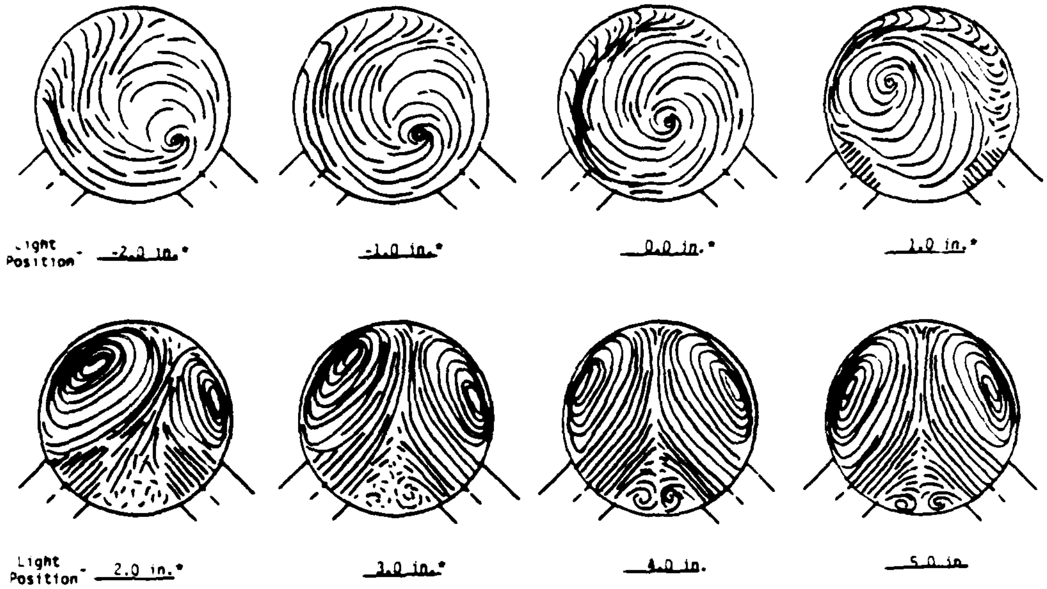
Another study conducted utilizing visual observation methods was the preliminary investigation into the effects of gas generator flows upon the basic combustor flow fields. For this investigation the solid flat dome plate of the combustor was replaced with a flat dome plate which had a 1.187 inch diameter hole bored through it to allow for gas generator flow simulation. The hole was bored through the dome plate half way between the dome plate's center and it's outer edge. The dome plate could be rotated in the combustor section in increments of 45 degrees. For this investigation only two positions of the gas generator port were studied. One position was at the 0.0 degree radial position which placed the port above the combustor axis and the second position was at 180 degrees which placed the port below the combustor axis. A combustor dome plate location of -2.0 inches was the only station observed in this initial investigation. The Water Tunnel total flow rate was 300 gallons per minute with 20 percent of the flow going through the gas generator port. Sketches of observed flows are shown in Figures 17 and 18 for the gas generator port in the top and bottom positions respectively.

* - FLOW DIRECTION OBSERVED IN BOTH CLOCKWISE AND COUNTER CLOCKWISE DIRECTIONS.

Dome Plate Location at 0.0 Inches

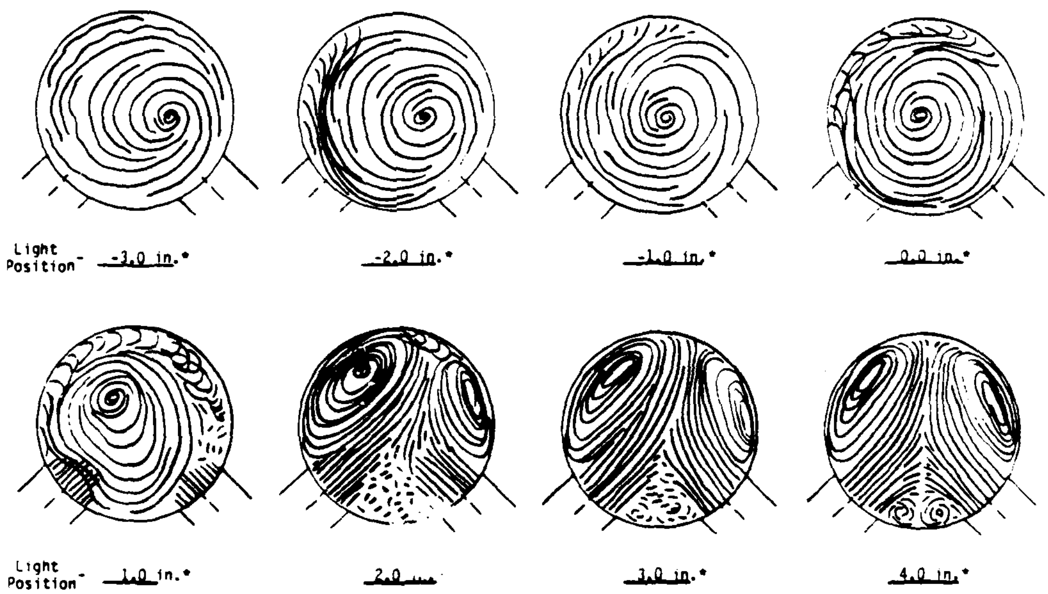
Dome Plate Location at -1.0 Inches

Figure 12. 30 Degree Inlet Configuration Flow Pattern Sketches



* - FLOW DIRECTION OBSERVED IN BOTH CLOCKWISE AND COUNTER CLOCKWISE DIRECTIONS.

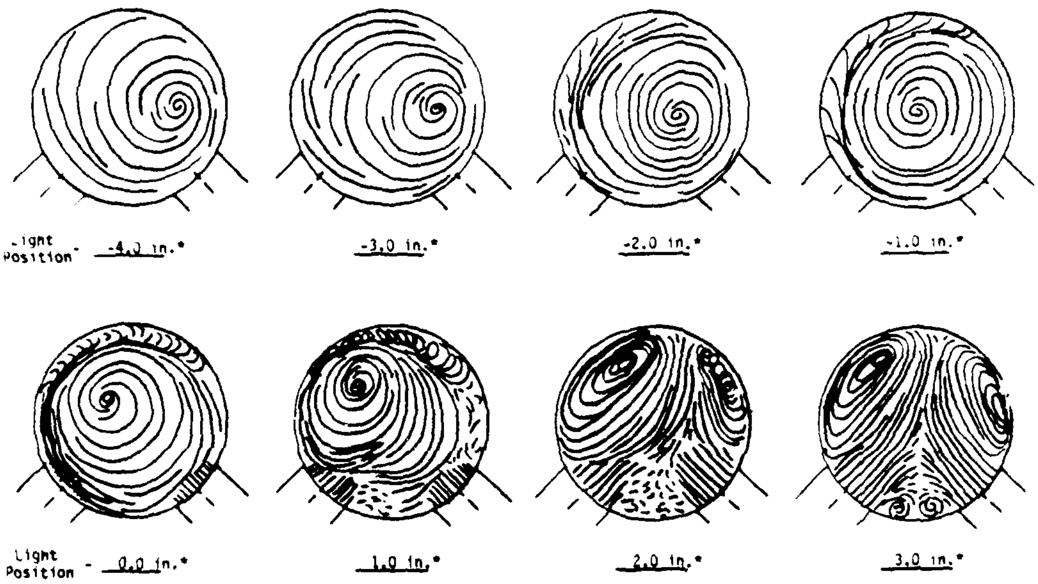
Dome Plate Location at -2.0 Inches



* - FLOW DIRECTION OBSERVED IN BOTH CLOCKWISE AND COUNTER CLOCKWISE DIRECTIONS.

Dome Plate Location at -3.0 Inches

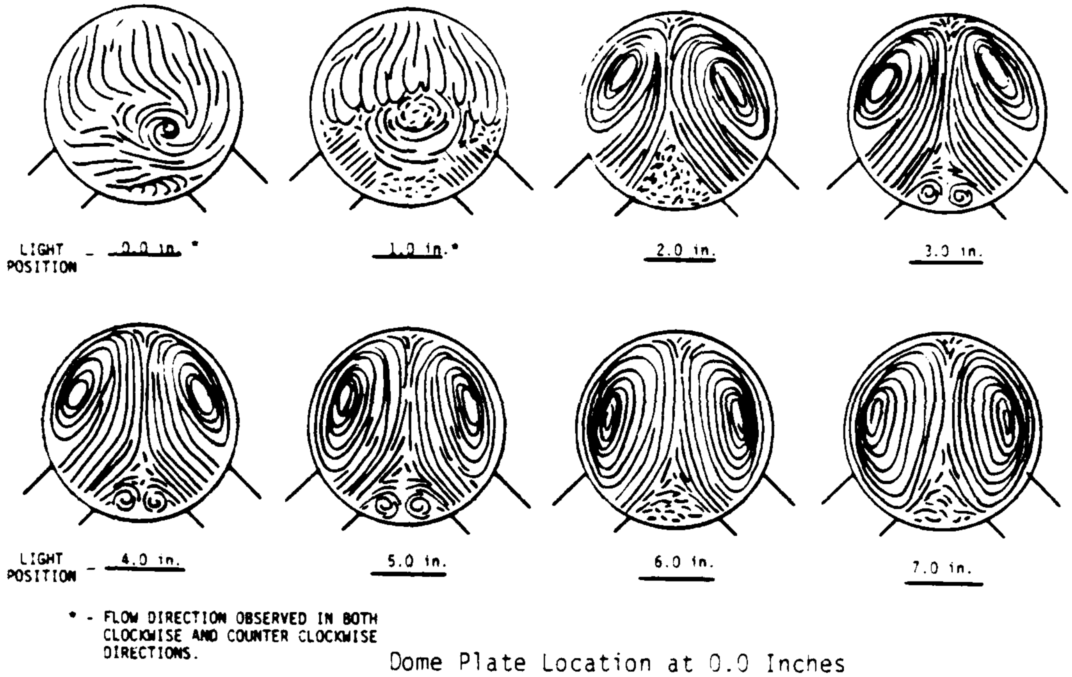
Figure 12. 30 Degree Inlet Configuration Flow Pattern Sketches (Continued)



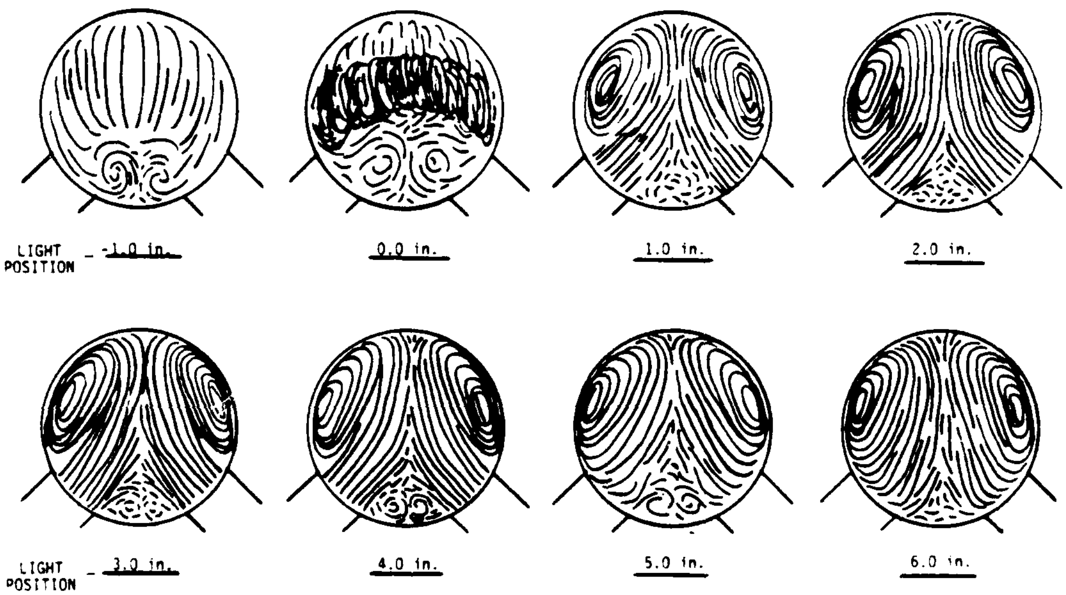
* - FLOW DIRECTION OBSERVED IN BOTH CLOCKWISE AND COUNTER CLOCKWISE DIRECTIONS.

Dome Plate Location at -4.0 Inches

Figure 12. 30 Degree Inlet Configuration Flow Pattern Sketches (Concluded)

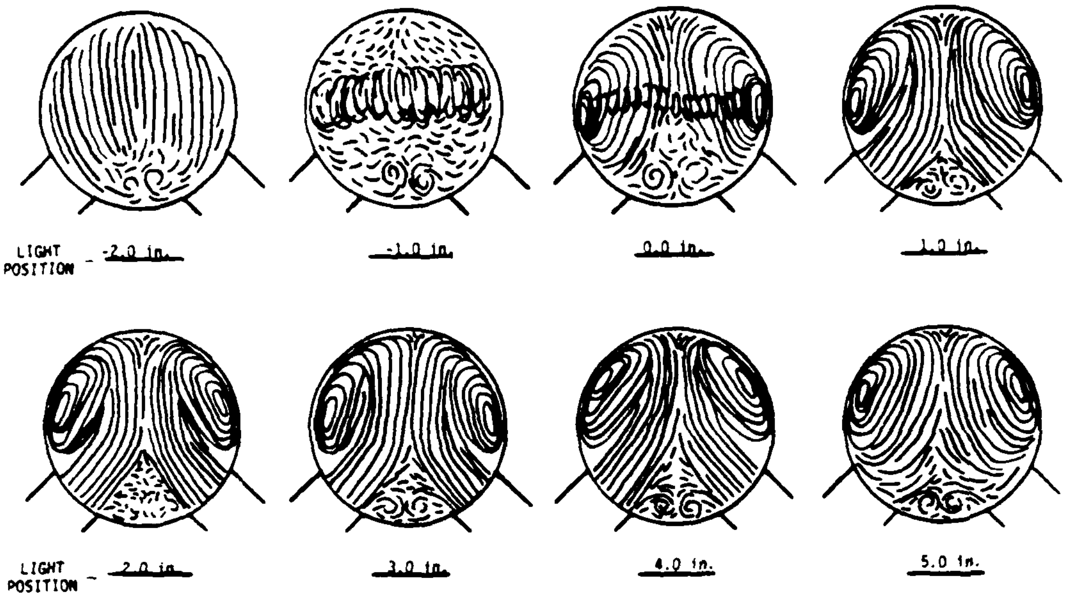


Dome Plate Location at 0.0 Inches

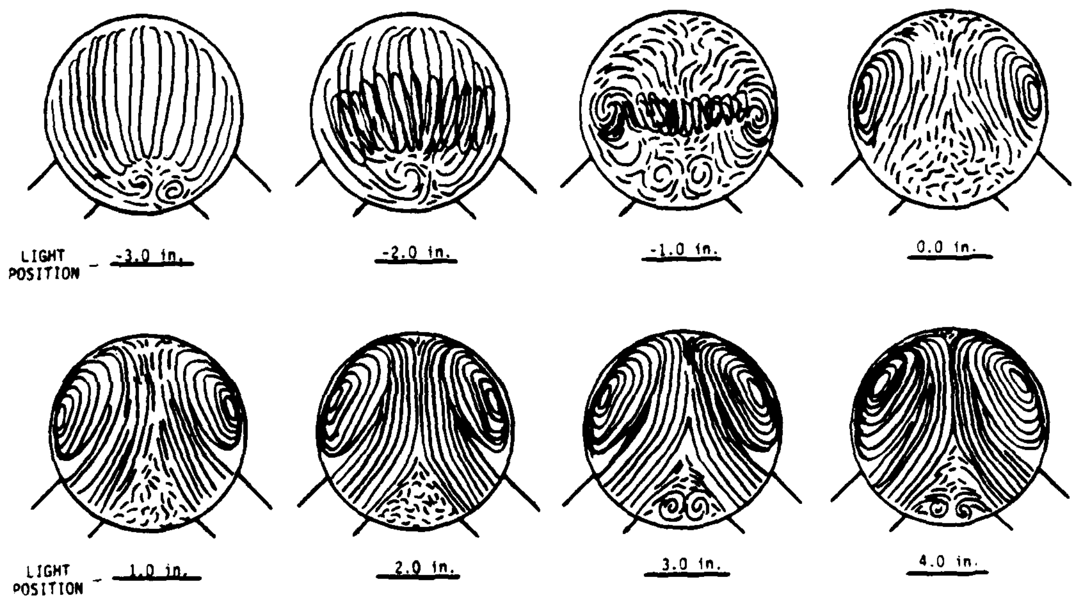


Dome Plate Location at -1.0 Inches

Figure 13. 45 Degree Inlet Configuration Flow Pattern Sketches

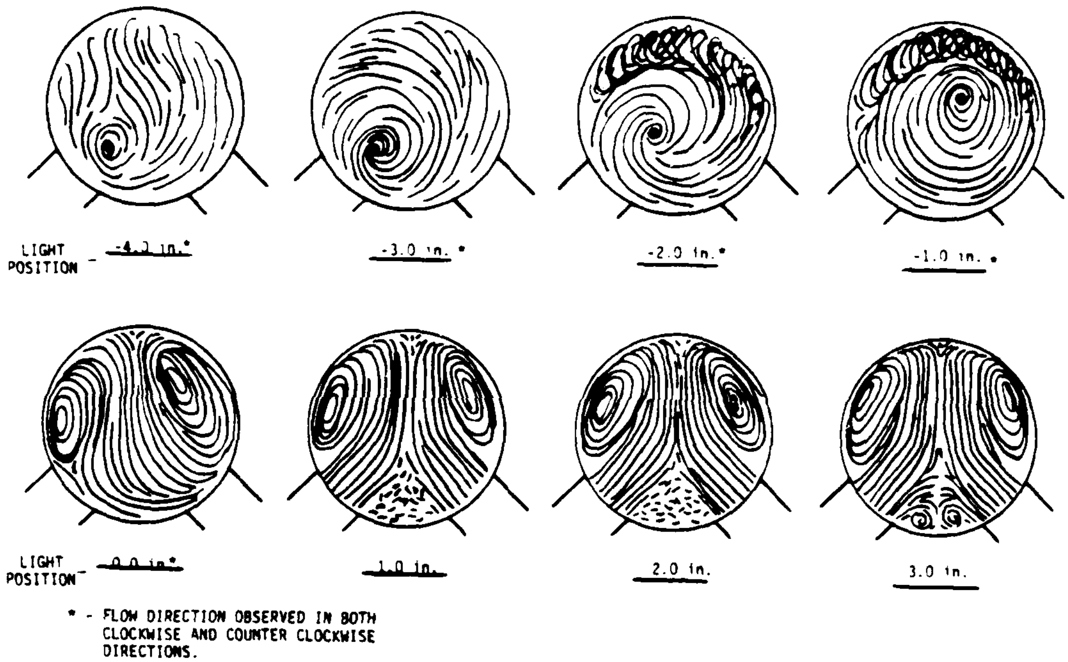


Dome Plate Location at -2.0 Inches



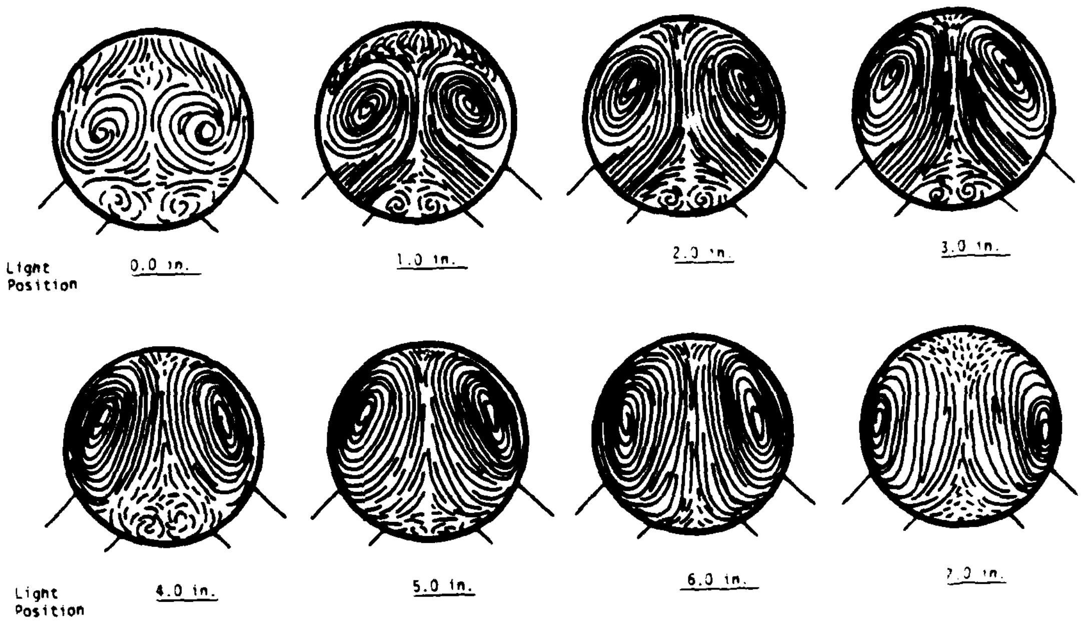
Dome Plate Location at -3.0 Inches

Figure 13. 45 Degree Inlet Configuration Flow Patterns Sketches (Continued)

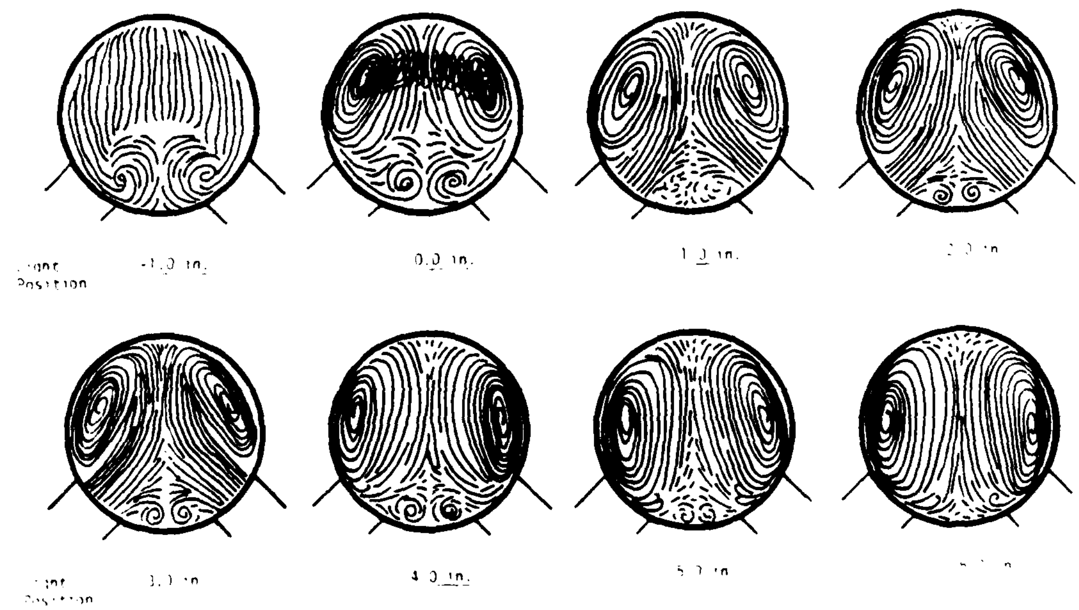


Dome Plate Location at -4.0 Inches

Figure 13. 45 Degree Inlet Configuration Flow Patterns Sketches (Concluded)

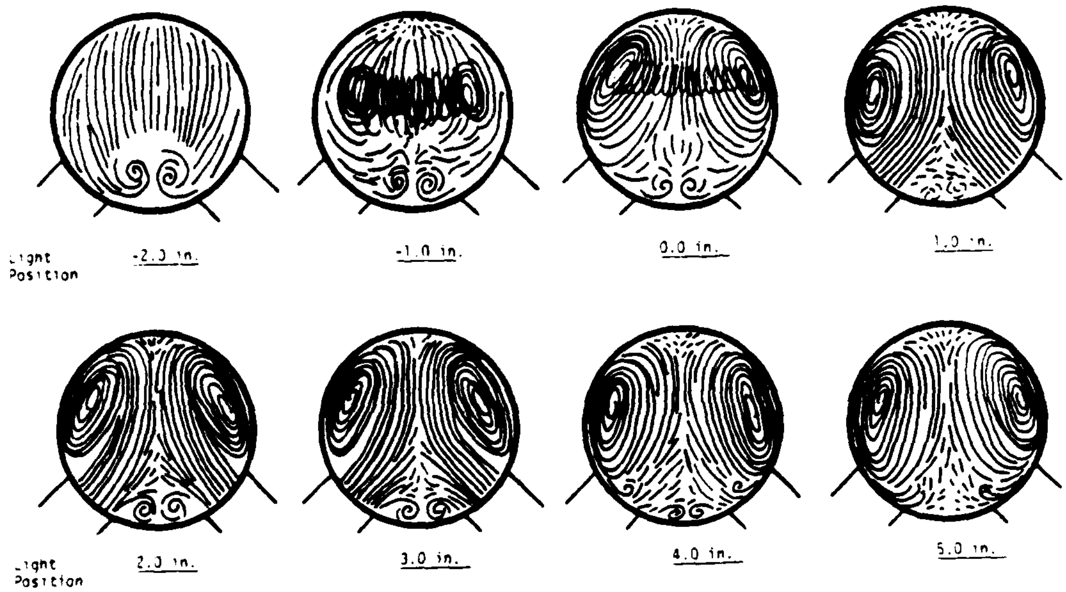


Dome Plate Location at 0.0 Inches

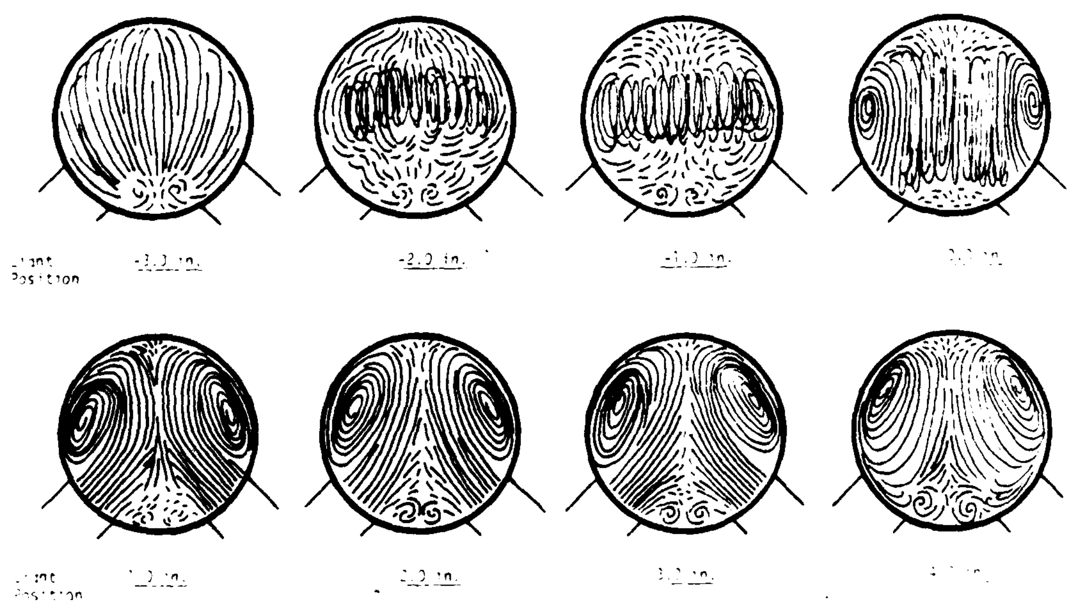


Dome Plate Location at -1.0 Inches

Figure 14. [illegible] Degree Inlet Configuration Flow Patterns [illegible]

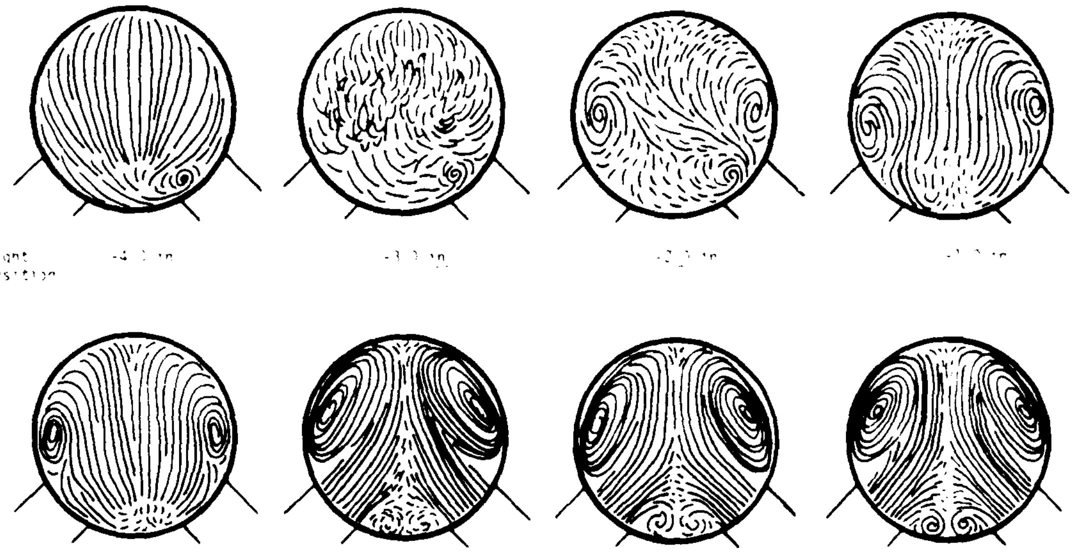


Dome Plate Location at -2.0 Inches



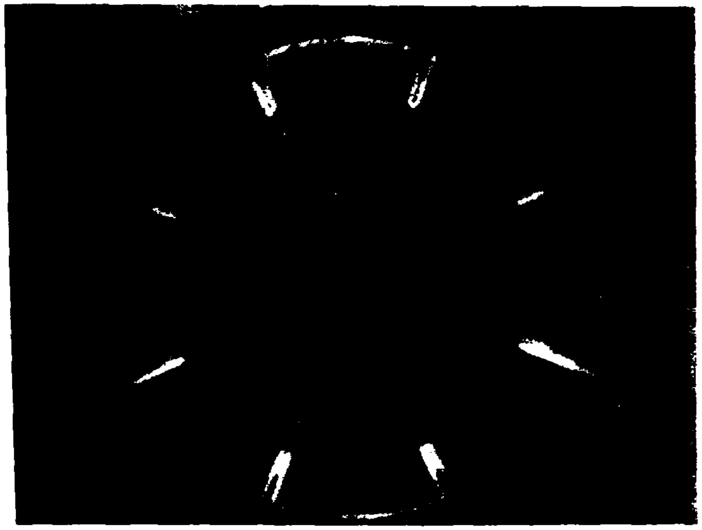
Dome Plate Location at -3.0 Inches

Figure 14. 60 Degree Inlet Configuration Flow Patterns Sketches (Continued)



Dome Plate Location at -4.0 Inches

Figure 14. 45 Degree Inlet Configuration Flow Patterns Sketches (Concluded)



Dome Plate Location at -2.0 Inches
Light Position at -2 Inches

Dome Plate Location at -2.0 Inches
Light Position at 0 Inches

Dome Plate Location at -2.0 Inches
Light Position at +2 Inches

Dome Plate Location at -2.0 Inches
Light Position at +8 Inches

Figure 15. Photographs of Flow Patterns Using Air Bubbles for the 60 Degree Inlet Configuration

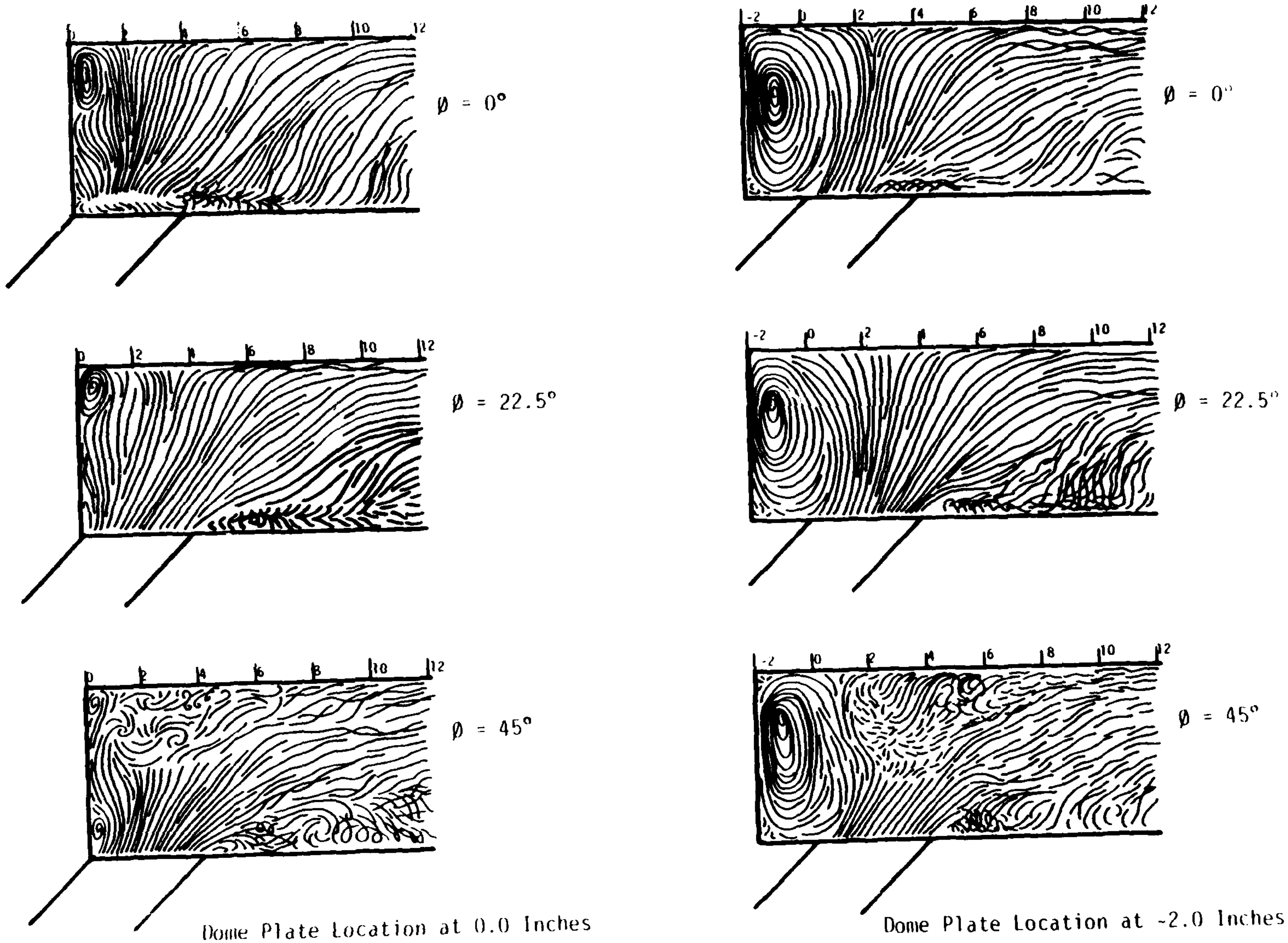


Figure 16. Radial Flow Pattern Sketches of the 60 Degree Inlet Configuration

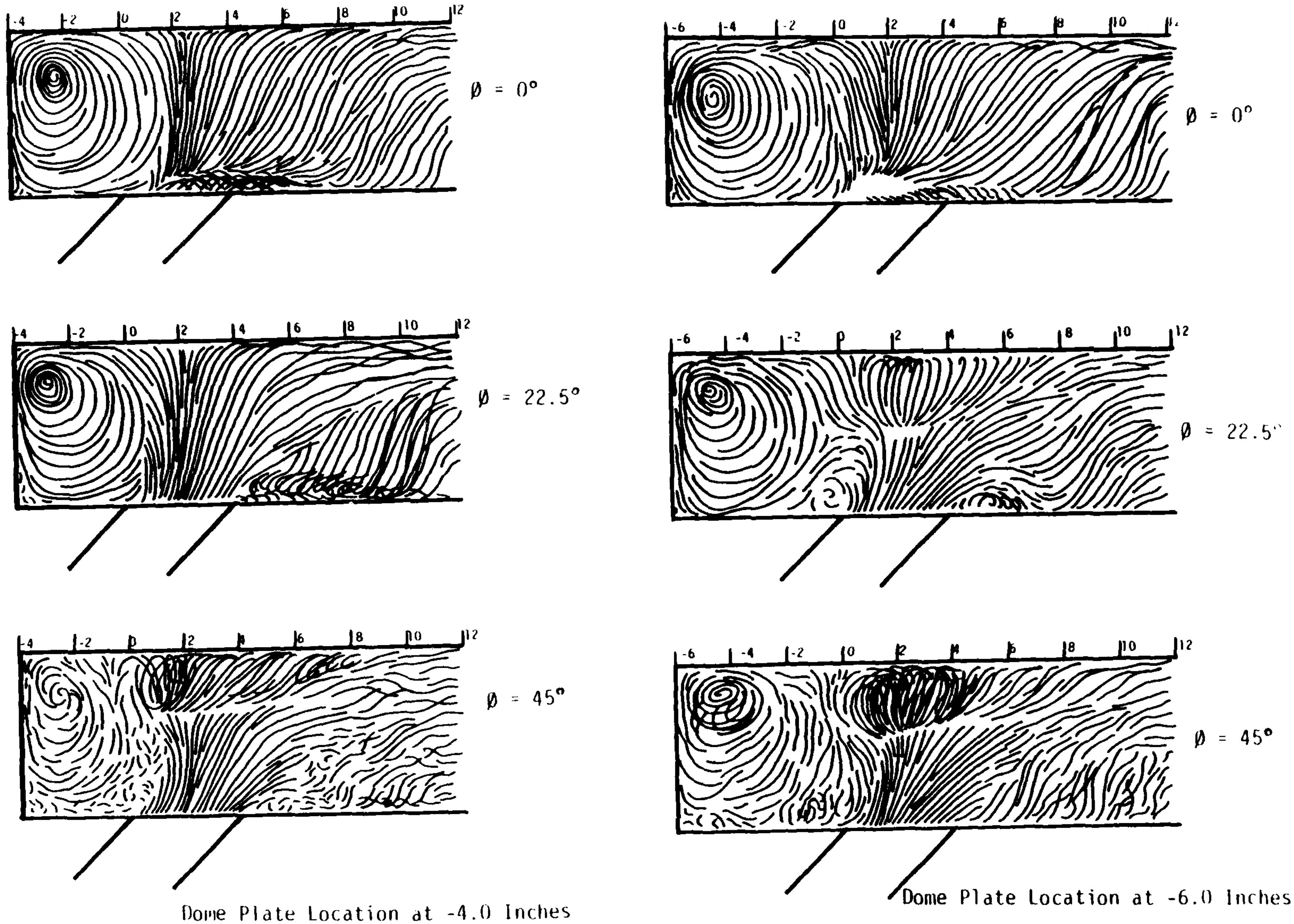


Figure 16. Radial Flow Pattern Sketches of the 60 Degree Inlet Configuration (Concluded)

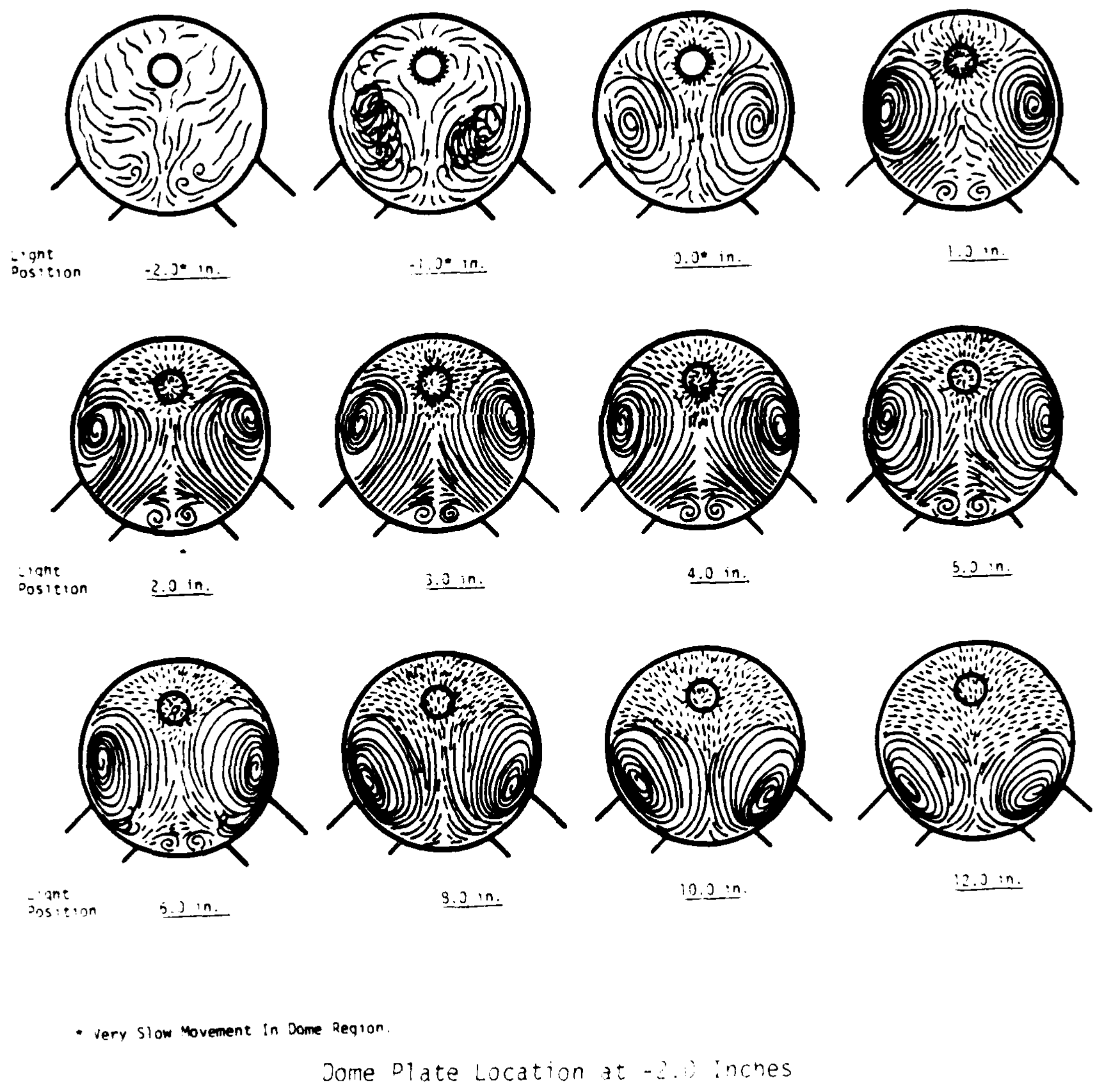
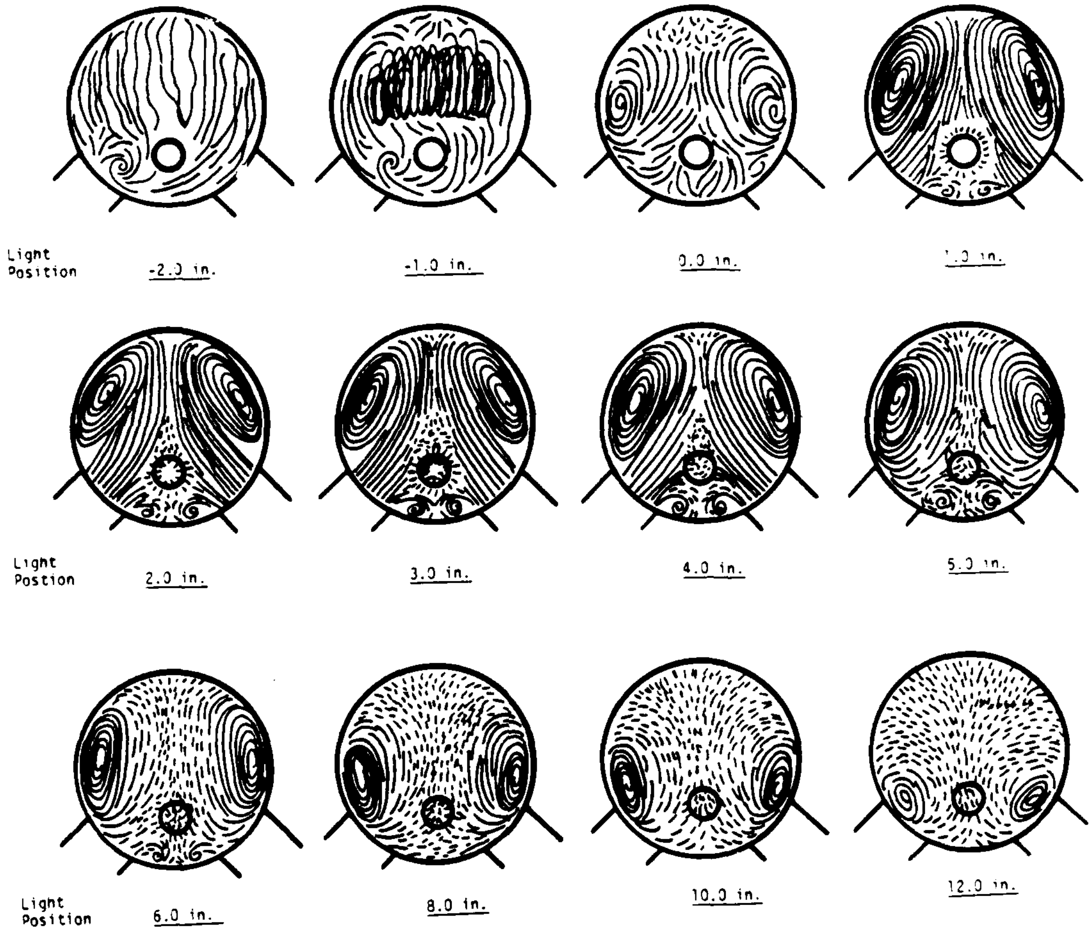


Figure 17. Sketches of 45 Degree Inlet Configuration Flow Patterns With 20 Percent Gas Generator Flow Through Port Above Combustor Axis



Dome Plate Location at -2.0 Inches

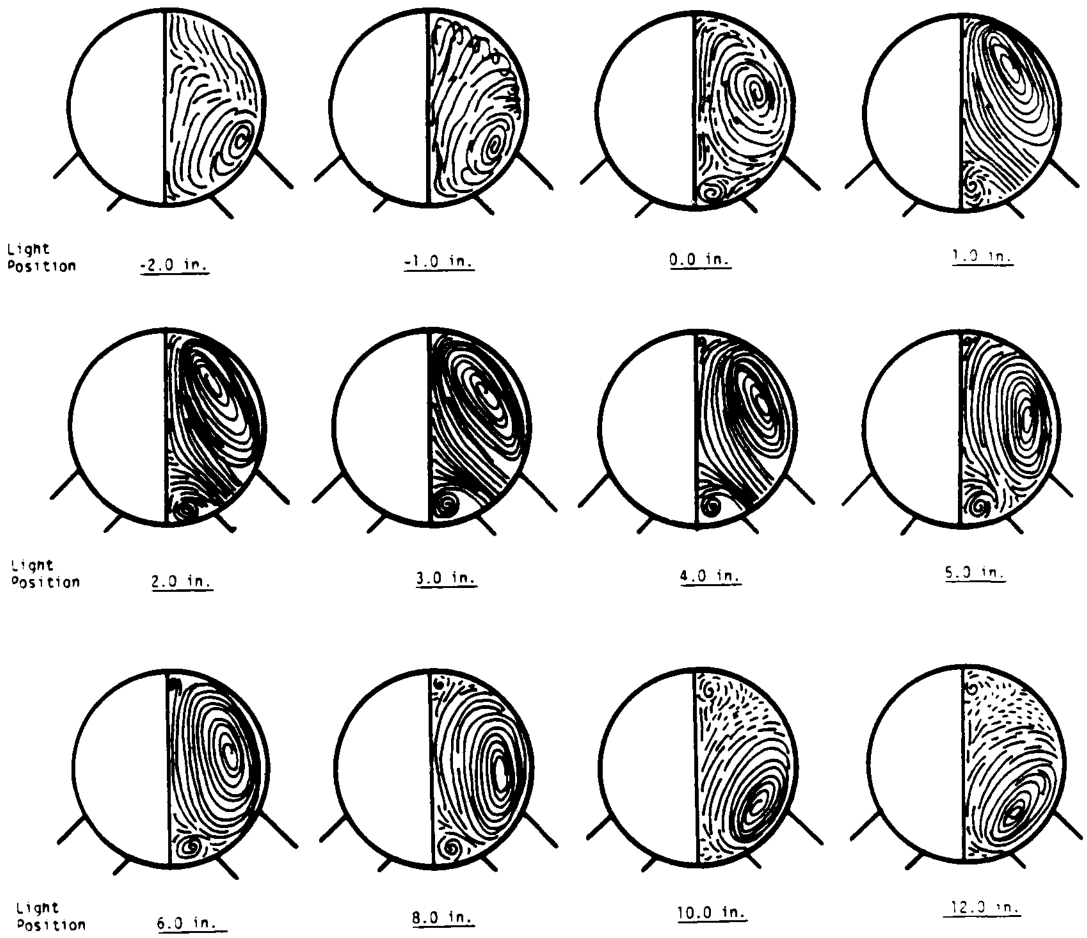
Figure 18. Sketches of 45 Degree Inlet Configuration Flow Patterns With 20 Percent Gas Generator Flow Through Port Below Combustor Axis

Another visual observation study that was undertaken was an investigation to examine the differences in the combustor flow field patterns for dual inlet and symmetry flows. In the computer simulation studies described in Section II use was made of combustor symmetry in order to reduce the total number of node points to be calculated and to reduce computation time. Therefore, it was of interest to examine what differences, if any, could be observed with Water Tunnel flows between the two interacting inlet flows and flow for one inlet. For this investigation a flow divider was placed in a modified dome plate and placed in the combustor configuration on the verical axis of symmetry. The divider was 13 inches long and extended into the combustor section several inches past the inlet openings. It was felt that this would be a good simulation of single inlet symmetry flow since the two inlet flows could not interact in the head end of the combustor. Shown in Figures 19 and 20 are sketches of flow field patterns for the 45 degree inlet configuration for dome plate locations of -2.0 and -4.0 inches respectively. These sketches should be compared with the sketches of flow patterns in Figure 13 to note the differences between dual inlet and symmetry flows. Figure 21 presents representative photographs of combustor flow patterns for divider flows at the two dome plate locations tested.

7.3 RESIDENCE TIME TESTING

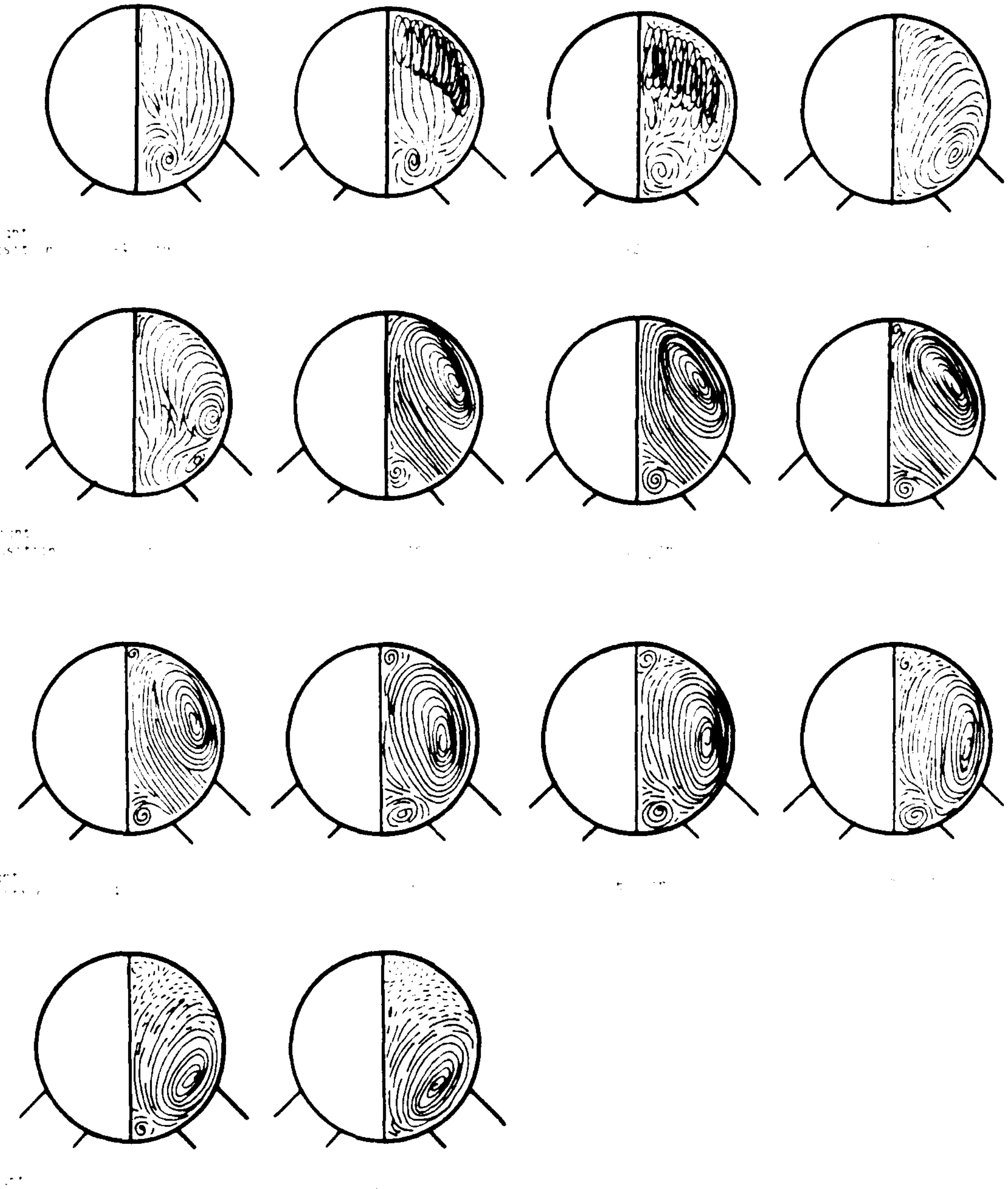
Test efforts were completed during this report period to obtain residence time data for the dual inlet side dump combustor configuration. The test configuration, described in Figure 3, was studied in an effort to determine the effect upon residence times of various configuration parameters. Water Tunnel residence times were obtained for different water tunnel flow rates to examine Reynolds number effects; for variations in the inlet duct angles; and for a range of combustor dome plate positions.

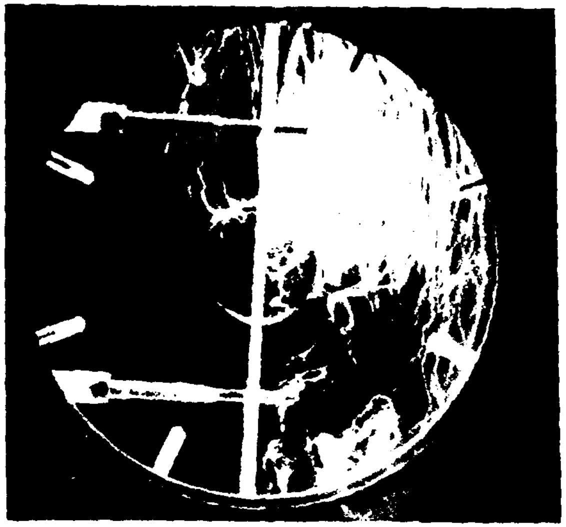
Residence times were calculated using dye tracer injection concentration-time data using the stimulus-response technique as described in Reference 3. An injected dye tracer pulse was the stimulus supplied to the system. The response of the system to the stimulus was obtained by detecting the variations in dye concentrations at inlet and



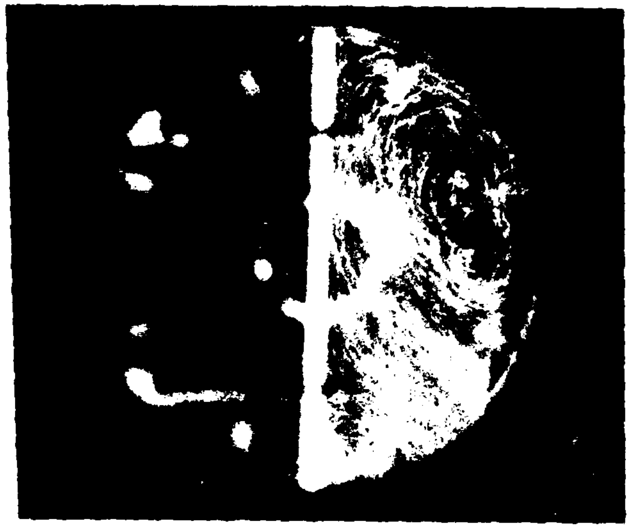
Dome Plate Location at -2.0 Inches

Figure 19. Sketches of 45 Degree Inlet Configuration Flow Patterns With Centerline Divider Installed Dome Plate Location -2.0 Inches





Light Position - -4.0 Inches



Light Position - +2.0 Inches

Light Position - +4.0 Inches

Dome Plate Location at -4.0 Inches

Figure 21. Photographs of 45 Degree Inlet Configuration Flow Patterns For Dome Plate Locations of -2 and -4 Inches With Centerline Divider Installed (Concluded)

exit points of the combustor. The concentration-time functions were then reduced to determine residence times and other statistical information. The measured residence times were then analyzed to determine the effects of combustor design parameters and to understand the dispersion characteristics of the combustor system.

7.3.1 Residence Time Test Results

Data were obtained for the three inlet angle configurations (30, 45, and 60 degrees) at Water Tunnel total flow rates of 200, 300, and 400 gallons per minute and for combustor dome plate positions of from 0.0 to -6.0 inches. Tests were conducted for dome plate positions in 0.5 inch increments for the 300 gallon per minute flow rate condition and in 1.0 inch increments for the 200 and 400 gallon per minute flow rates. All tests were conducted at a tunnel water temperature of 80-90 degrees Fahrenheit. The inlet duct Reynolds numbers for the three Water Tunnel flow conditions are presented in Table 1.

Presented in Figure 22 are plots of measured and calculated residence times versus dome plate positions for the three inlet angle configurations and for the three tunnel flow rate conditions. Shown in Figure 23 are plots of the measured and calculated residence times versus inlet Reynolds number for dome plate positions of 0.0 and -6.0 inches .

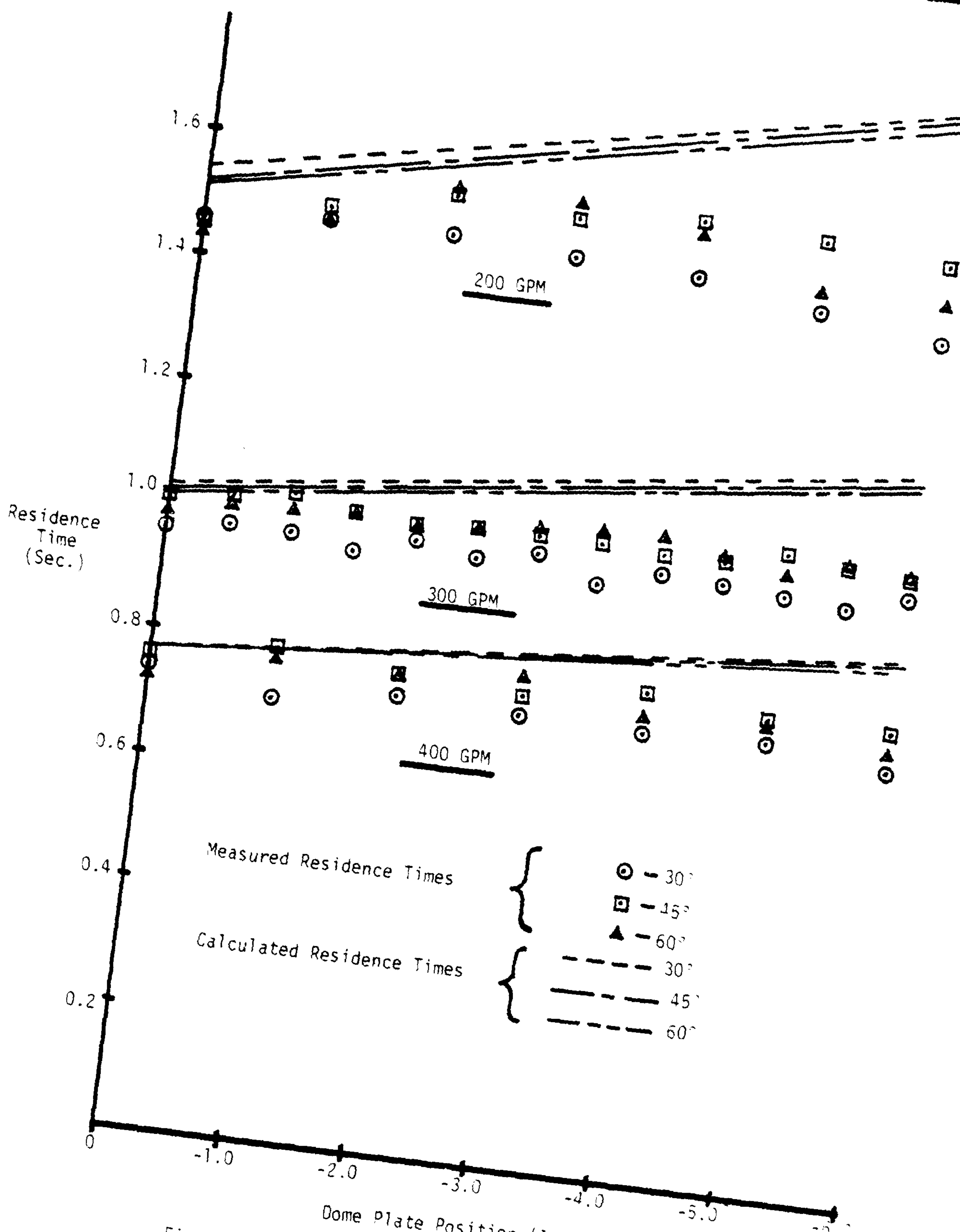


Figure 22. Residence Times Versus Dome Plate Position

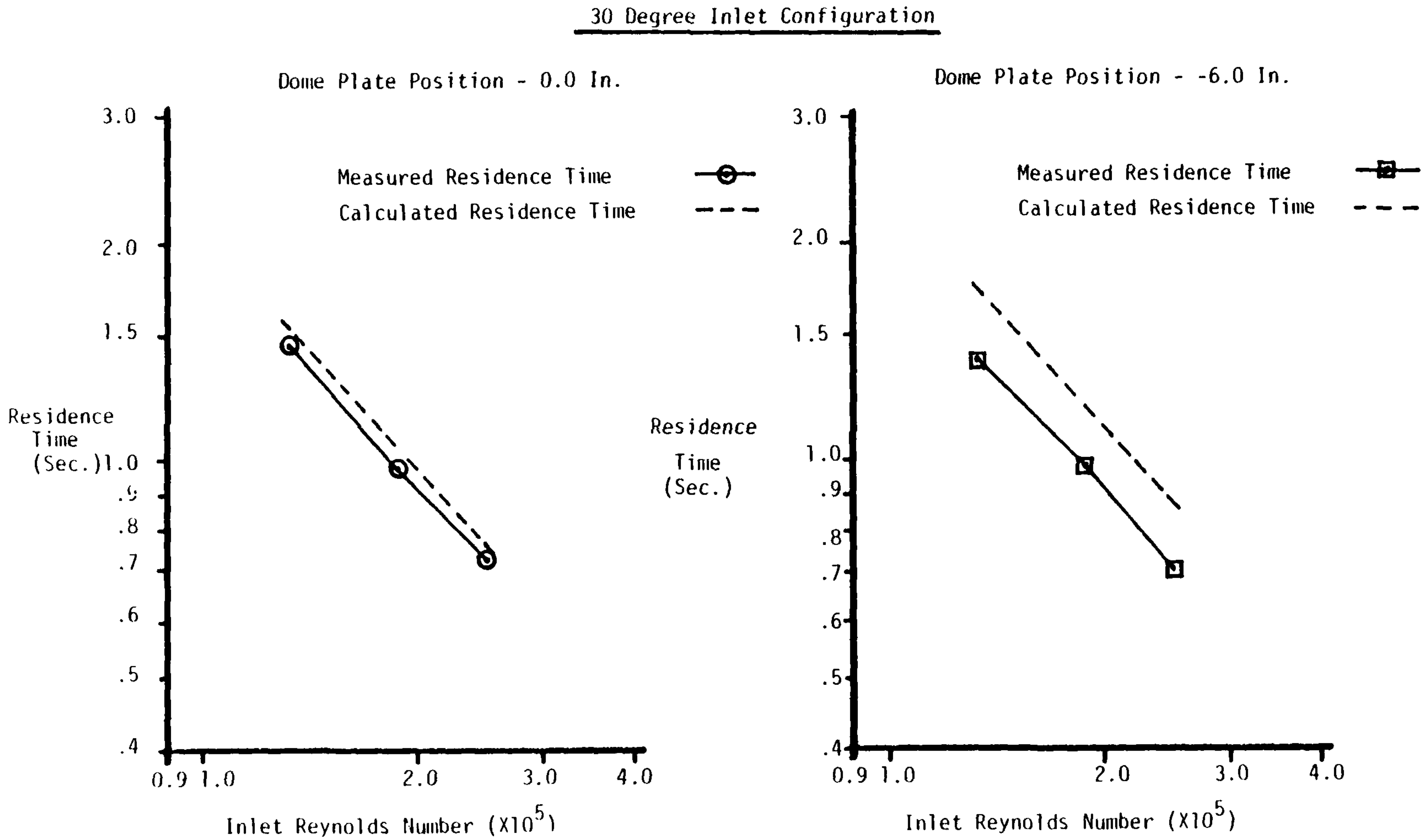


Figure 23. Residence Times Versus Inlet Reynolds Numbers

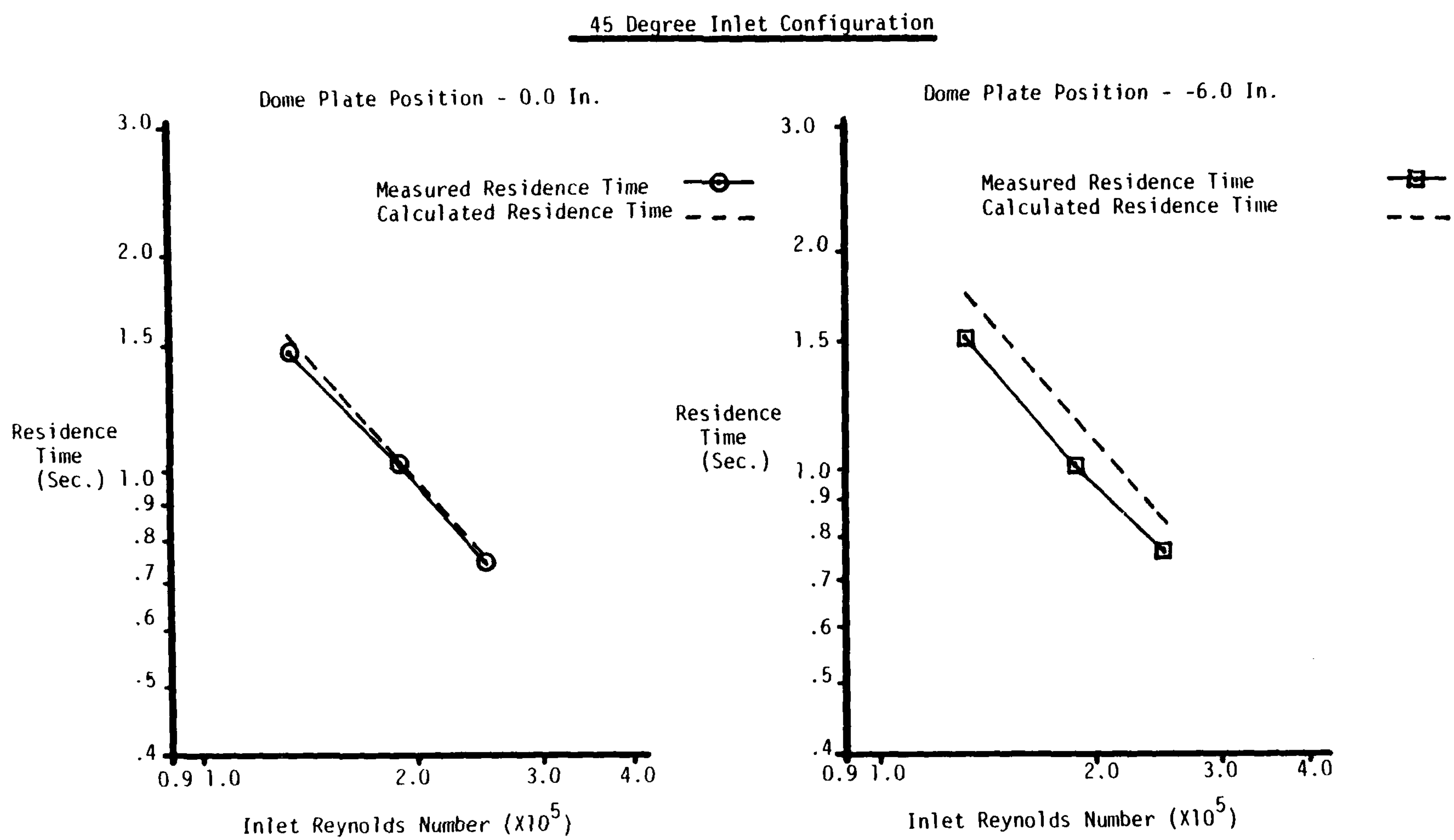


Figure 23. Residence Times Versus Inlet Reynolds Number (Continued)

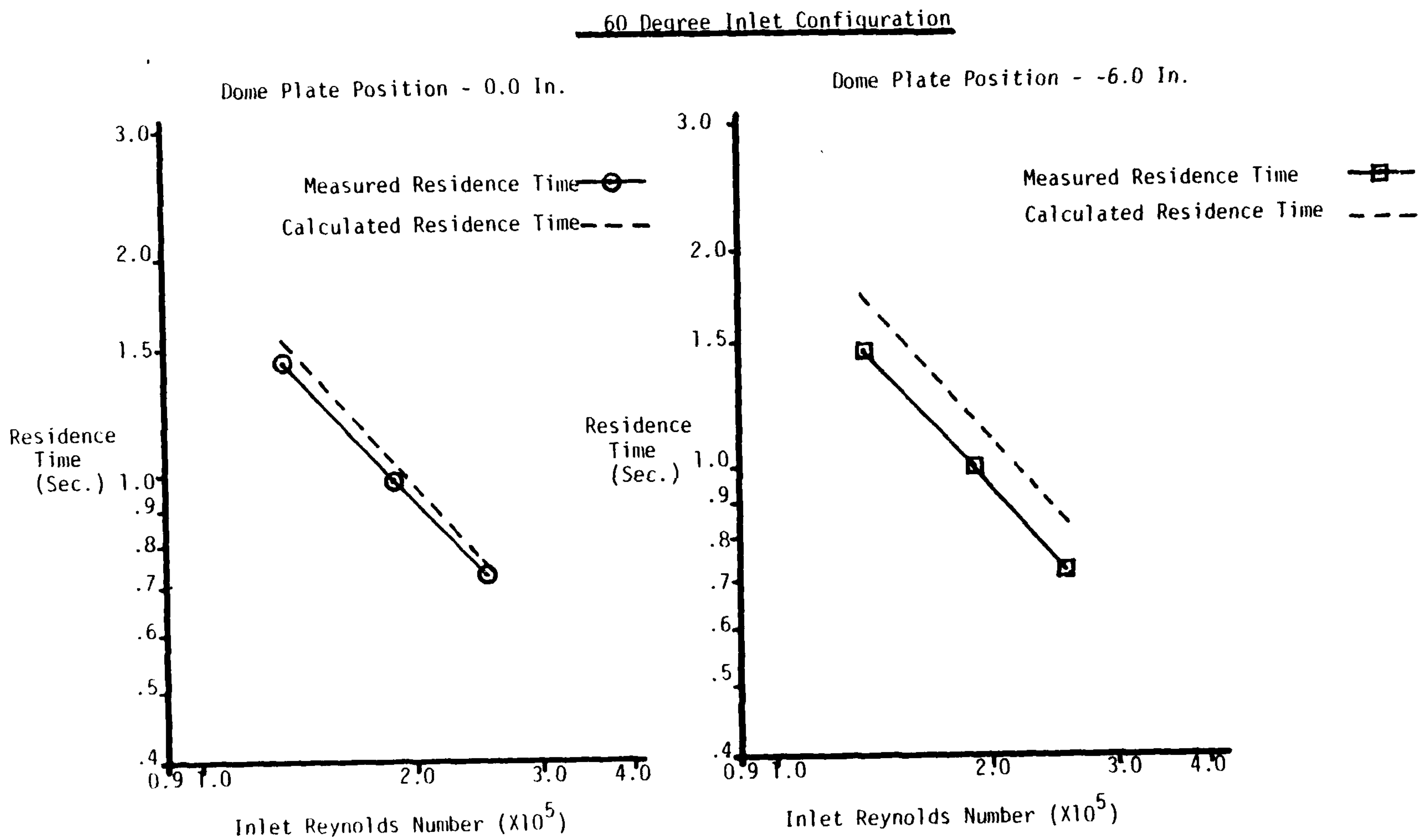


Figure 23. Residence Times Versus Inlet Reynolds Numbers (Concluded)

SECTION VIII
DISCUSSION OF RESULTS

The following paragraphs summarize the important points of interest arrived at from the analysis of results obtained in the conducting of visual and residence times studies of the dual inlet side dump combustor configurations.

8.1 VISUAL DATA OBSERVATIONS

From the analysis of visual and photographic data for the various configurations of the multi-ducted inlet combustor it can be seen that the AFWAL/PORT Water Tunnel facility has tremendous potential for providing qualitative and quantitative data of cold flow simulations. The cross-sectional sketches of flow field patterns reveal the formation of strong inlet vorticies at each inlet and the characteristics of these vorticies in the dome region as the inlet angle and dome plate position are varied. From visual observations it appears that from the combustor inlets to the exit nozzle the flow patterns are almost identical for variations in both the inlet angle and dome plate position. The major flow field differences were observed to occur forward of the combustor inlets in the dome region.

For the 30 degree inlet configuration, the dome region flow pattern sketches show that the inlet vorticies are joined together in the dome region for dome plate positions of 0 to -1.0 inches. When the dome plate was beyond the -1.0 inch position the vortex separates apart resulting in one vortex attaching to the opposite side of the dome plate. The vortex that does not attach to the dome plate appears to be forced to the top of the combustor and to the outside of the attached vortex. For the 45 degree inlet configuration the vortex again separates but not until the dome plate goes beyond the -4.0 inch dome plate position. It should be pointed out that with balanced inlet flows to the combustor the attached vortex developed from either inlet vortex.

The 60 degree inlet configuration flow pattern sketches reveal a somewhat different flow process in the dome region. When the dome plate was at the 0 inch position the inlet vorticies were separated and attached to the dome plate. As the dome plate was moved to a greater

depth the two vorticies joined as previously described for the other configurations. The vorticies stayed joined for dome plate positions from -1.0 to -6.0 inches. The vortex separation did not occur until the dome plate position was greater than -6.0 inches. The radial flow pattern sketches presented in Figure 16 for the 60 degree inlet configuration give another perspective into the flow processes that occur in the dome region as the dome plate is moved forward of the inlet ducts.

The preliminary investigations into gas generator effects and symmetry flows demonstrate the future areas of interest that may be studied utilizing the Water Tunnel test rig. From examination of gas generator flow patterns it appears the gas generator has a great deal of effect upon combustor flow fields in the dome region. This was especially evident when the gas generator injection was above the centerline of the combustor. For that case the injected flow reduced the dome circulation and caused the inlet vorticies to be moved down from the top of the combustor. Additional studies of gas generator flows will be required to determine effects on residence time and combustor flow patterns.

The study of symmetry flows revealed that the use of symmetry flows for simulations may not be entirely correct for interacting flows. Some differences in the dome region flow patterns were noted between dual inlet and divider flows. This result may have to be considered when computer simulations are being derived using flow symmetry in the analysis of combustor processes.

8.2 DISCUSSION OF RESIDENCE TIME RESULTS

The residence time of a reactor or combustor as defined in equation (1) is the combustor volume divided by the fluid flow rate through the combustor. Therefore, for a known fluid flow rate the measured residence times is the apparent volume divided by the flow rate as given in (2). From this it can be shown that the ratio of measured to calculated residence times is equal to the ratio of apparent combustor volume to actual combustor volume (3). Any differences between the actual and apparent combustor volumes relates to stagnate or non-reactive portions of the combustor.

$$\text{Calculated Residence Time: } T_{R_C} = \frac{\text{Volume}_{\text{actual}}}{\dot{V}\ \text{actual}} \qquad (1)$$

$$\text{Measured Residence Time: } T_{R_M} = \frac{\text{Volume}_{\text{apparent}}}{\dot{V}\ \text{measured}} \qquad (2)$$

for $\dot{V}$ actual - $\dot{V}$ measured

$$\frac{\text{Volume}_{\text{actual}}}{T_{R_C}} = \frac{V_{\text{apparent}}}{T_{R_M}}$$

then

$$\frac{T_{R_M}}{T_{R_C}} = \frac{\text{Volume}_{\text{apparent}}}{\text{Volume}_{\text{actual}}} \qquad (3)$$

Presented in Figure 24 are plots of measured to calculated residence time ratios versus combustor dome plate positions for the inlet angles and flow rates tested. In all cases, the ratios of measured to calculated residence times decreased as the combustor dome plate was moved upstream of the inlets increasing dome region volume. This means that the apparent combustor volume decreases for an increase in the volume of the dome region. This decrease in apparent volume was found to be greatest for the 30 degree inlet configuration. The 45 degree inlet configuration showed the least decrease in apparent combustor volume. Also shown on each of the plots are the dome plate positions beyond which the dome region vorticies were observed to be separated and attached to the dome plate. Plots for the 45 and 60 degree inlet configurations show that measured residence times almost equal the calculated values for dome plate positions from 0 to -1 inches. Therefore, for these configurations and dome plate positions the stagnation volume would be minimum.

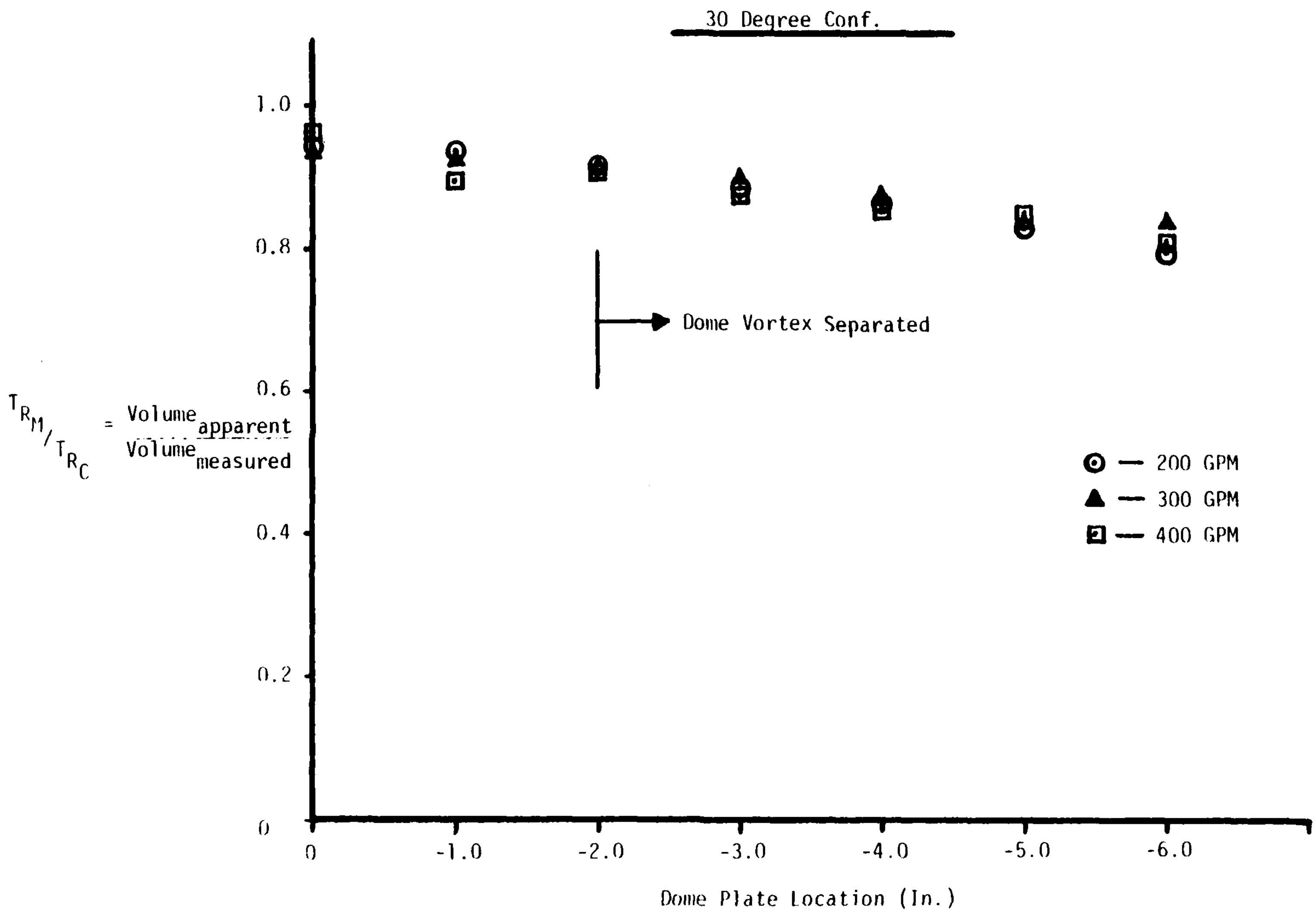


Figure 24. Ratio of Apparent Combustor Volume To Actual Combustor Volume Versus Dome Plate Position

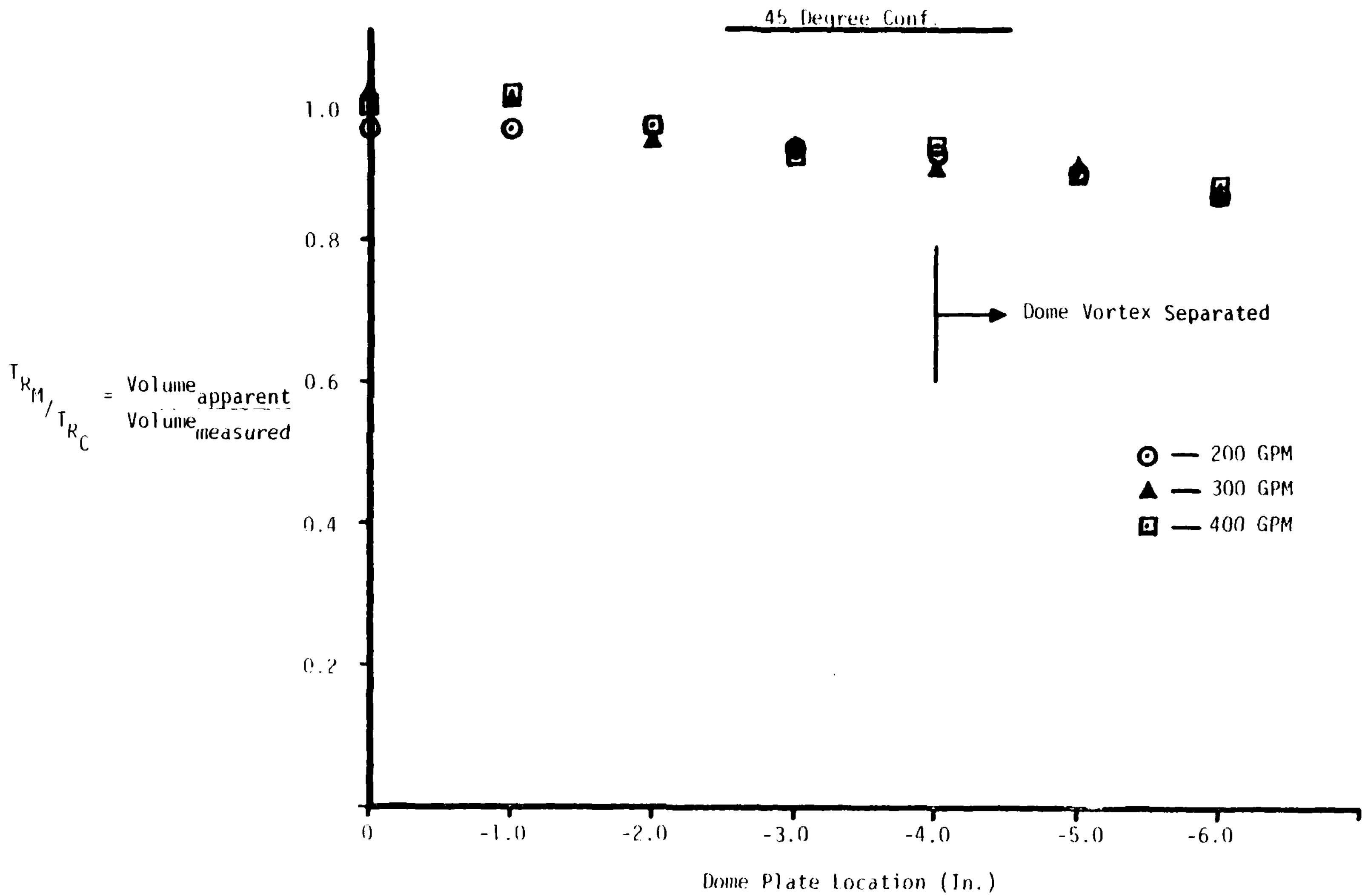


Figure 24. Ratio of Apparent Combustor Volume To Actual Combustor Volume Versus Dome Plate Position (Continued)

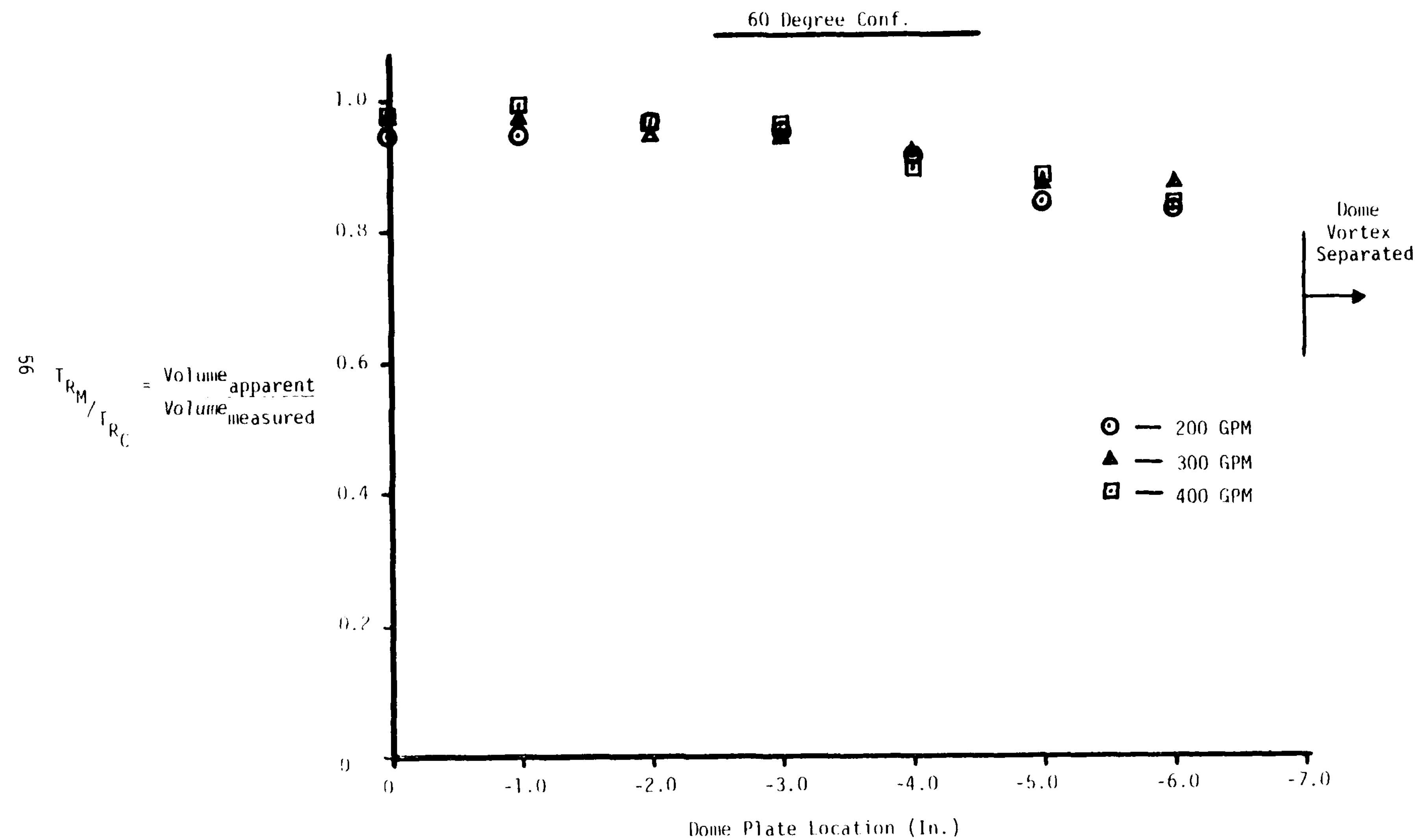


Figure 24. Ratio of Apparent Combustor Volume To Actual Combustor Volume Versus of Dome Plate Position (Concluded)

SECTION IX
CONCLUSIONS

UES efforts are continuing in order to conduct research and development of advanced ramjet combustors utilizing the AFWAL/PORT Water Tunnel test rig. Since the program has not yet been completed only limited conclusions can be derived for the test results which have been obtained. Some results reported herein were from preliminary investigations and will require further study and analysis. Conclusions can be made regarding the visual and residence time data that was obtained for the basic configuration of the dual inlet side dump combustor.

9.1 VISUAL STUDY CONCLUSIONS

The visual data obtained from the Water Tunnel demonstrate the capabilities of the facility for displaying fluid flow characteristics of complex configurations. Visual observations showed that the flow within the side dump combustor is made up of two primary regions. One region is from the combustor inlets to the combustor nozzle. In this region the flow consists of two large vorticies generated by the inlet flows. These large vorticies form above the combustor centerline and gradually move to the bottom of the combustor dissipating down the length of the combustor. The strength of these vorticies decreases greatly within a few inches past the combustor inlets. There appeared to be very little effect upon this region of the combustor due to changes in inlet angle and dome plate position.

The second flow region was the area from the inlet ducts to the combustor dome plate. The flow in this region was greatly affected by inlet angle and dome plate position. For each inlet angle configuration there was a range of dome positions for which a dome circulation due to the linkup of the two inlet vorticies was present. When the dome plate was moved beyond a certain point, determined by inlet angle, the link between the two vorticies would break. When this break would occur, one of the vorticies would attach to the dome plate and the other vortex would dissipate around it. This was observed to occur from either side of the combustor with balanced inlet flows.

The visual data obtained of combustor flow fields can be utilized in the analysis of flow processes within actual combustors and provide verification to computer analysis and simulation.

9.2 RESIDENCE TIME CONCLUSIONS

Residence time data was utilized to make a number of conclusions regarding the flow processes of combustor configurations regarding Reynolds number, dome height, and inlet duct angles. For variations in Reynolds number the only difference between calculated and measured residence times was a shift in the residence time versus Reynolds number curves due to dome height changes. The only change in residence times due to Reynolds number resulted from the change in the fluid flow rate to obtain the desired Reynolds number. Another conclusion arrived at was that the measured residence times were almost constant for the range of dome plate position that were tested. This was the case for each of the inlet duct angles tested. Residence time data also revealed that the apparent combustor volume decreases when the dome region volume is increased or when the combustor inlet angle decreases.

Additional analysis of residence time data will provide a more complete understanding of combustor cold flow processes and aid in the design of advanced combustors. These efforts will also aid in the computer simulations studies being undertaken.

REFERENCES

1. S. P. Vanka, Analytical Characterization of Flowfield in Combustor Configurations, UES Number UES-TR-82-728-01 , Universal Energy Systems, Inc., Dayton, Ohio, October, 1982.

2. James E. Craig, Holography Diagnostic Techniques for Ramjet Flows, SDL Number 83-2239-01F, Spectron Development Laboratories, Inc., Costa Mesa, California, March, 1983.

3. O. Levenspiel, Chemical Reaction Engineering, John Wiley and Sons, 1962.

*USGPO: 1983-759-062-586

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